

# **The Evidence-Base for Neurofeedback as a Reimbursable Healthcare Service to Treat Attention Deficit/Hyperactivity Disorder**

**By**

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## Executive Summary

This paper was commissioned by the Board of the International Society of Neurofeedback and Research (ISNR) to evaluate the evidence-base of neurofeedback (NFB) to treat Attention Deficit/Hyperactivity Disorder (ADHD), the most frequently diagnosed pediatric behavioral health disorder in America. It was the Board's assessment that there were no recent comprehensive reviews of the literature and several published reviews by authors without expertise in NFB evidenced apparent bias by holding NFB to a scientific standard that no other psychosocial treatment for ADHD or any other behavioral health disorder has ever met including ADHD treatments that they advocated for as being '*evidence based*' (see appendix).

As documented by the eight-year long NIMH-funded MTA Cooperative study, the gold standard study in ADHD treatment effectiveness research, optimal versions of the most commonly reimbursed treatments fail to result in sustained benefit for the majority of children. Surprisingly, in this study's 22-month follow-up assessment of the currently recognized best treatments for ADHD, no sustained benefit was evident for any of these treatments as compared to those ADHD children who had simply been referred to community-based professionals and may or may not have actually followed through with treatment from them. Even after 14 months of free intensive multi-component behavior therapy combined with systematic medication management followed by referral to community-based treatment professionals for continuing care, ADHD was found to be an ongoing debilitating illness and the societal costs that are associated with it included **10.4%** of such '*optimally-treated*' children requiring psychiatric hospitalization one or more times during follow-up. ***The psychiatric hospitalization rate for those receiving intensive multi-component behavior therapy without medication was even higher at 12.3% compared to only 8.3% of those who had simply been referred to community-based professionals.*** The MTA study results dramatically demonstrate that more effective treatments for ADHD are desperately needed and as such treatments are identified, they warrant reimbursement by healthcare insurers to foster their implementation.

ADHD is widely viewed as being associated with neuronal dysregulation resulting in high rates of inattentiveness, impulsivity, and often hyperactive behaviors in the children and adolescents diagnosed with this disorder. NFB is a form of behavior therapy with over 40 years of basic and applied research combining real-time measurement of neuronal electrical activity with the scientifically established principles of operant conditioning to teach trainees how to better self-regulate brain functioning. As such, if NFB can be successfully implemented with ADHD children it is uniquely suited to effectively treat the neuronal dysregulation that is common in this disorder.

Beginning in the early-1960s, neuroscientists demonstrated that decreases in the motor activity of cats was associated with increased 12-16hz neuronal electrical activity in the sensorimotor cortex, an activity pattern that Professor Maurice Serman from UCLA named the sensorimotor rhythm (SMR). Professor Serman and his colleagues found that when hungry cats were fed contingent upon the increase in SMR activity, the cats "became very alert" and displayed "an almost intense cessation of movement;" behaviors seldom seen in children with ADHD. Building on Dr. Serman's findings, in the mid-1970s using a scientifically rigorous research design in which both the child subjects and raters of

ADHD behaviors were blind to the experimental condition and the children acted as their own experimental controls, Professor Joel Lubar and colleagues demonstrated both 1) the functional relationship between SMR and the manifestation of the core behaviors associated with ADHD, and 2) that through real-time feedback of SMR activity levels paired with operant conditioning, children diagnosed with ADHD can learn to self-regulate SMR with the resulting improvements or worsening in their core ADHD symptoms based on whether they were being reinforced to increase or decrease their level of SMR neuronal activity.

Building on the neuroscience research foundation provided by Professors Maurice Serman and Joel Lubar, NFB's evidence-base continues to grow with **over 50 peer-reviewed journal articles published to date** documenting its effectiveness in treating ADHD's core symptoms. This paper reviews in detail the controlled studies published during the past decade evaluating NFB's effectiveness in treating children and adolescents with ADHD. Our review documents that not only has NFB been found to be superior to a variety of experimental control group conditions, but also in three studies NFB was found to be equivalent to stimulant medication in treating the core symptoms of ADHD. Furthermore, we found five studies that assessed whether or not NFB resulted in sustained benefits after treatment ended, including two studies with two-year follow-up assessments. In each of these follow-up assessments, the gains from NFB were maintained after treatment had ended and in one study had increased further during the two-year follow-up **such that half of the children no longer meet the diagnostic criteria for ADHD**. In contrast, stimulant medications' beneficial effects commonly cease when the medication is stopped, and as found in the MTA Cooperative study, the authors concluded that there was **no evidence** to support the **"long-term advantage of (continued) medication treatment beyond 2 years for the majority of children."** So while the MTA study findings, along with 50 years of research and clinical practice, clearly documents the near-term effectiveness of stimulant medications, the long-term benefits and risks from taking these medications are still not clear. Furthermore even during the near-term, one-third or more of children do not respond adequately to ADHD medications and/or have significant adverse side-effects from them heightening further the need for effective treatment alternatives.

Besides the findings from our review, independent evaluations of NFB's evidence-base are increasingly validating NFB's effectiveness in treating the core symptoms of ADHD. A recent meta-analysis found NFB to be **more than twice as effective** as the six other non-pharmacological ADHD treatments that were analyzed, and in October 2012, the company that maintains the American Academy of Pediatrics' ranking of research support for psychosocial treatments **awarded NFB the highest level of evidence-based support** for the treatment of ADHD. Given the generally poor long-term outcomes for the most commonly reimbursed ADHD treatments and NFB's substantial and growing evidence-base, NFB clearly warrants reimbursement by insurers for the treatment of ADHD thereby facilitating its wide-spread adoption.

## An Overview of Neurofeedback Practice

### **Key Points:**

- ***Neurofeedback is a form of behavior therapy that combines operant conditioning with real-time measurement of neuronal electrical activity to teach trainees how to better self-regulate brain functioning***
- ***As a form of behavior therapy, neurofeedback is a subtype of psychotherapy and the regulation of its practice to treat mental health disorders in the United States falls under the auspices of each state's licensing boards for the various mental health professions***
- ***While the practice of neurofeedback is regulated by each state's mental health licensing boards, the Biofeedback Certification International Alliance has developed a rigorous training curriculum and evaluation process to certify mental health professionals as being competent to provide neurofeedback services***
- ***While each case is different, the number of neurofeedback sessions necessary to achieve significant and sustained improvement typically ranges from 10 to 40 sessions, with 30 to 40 sessions the norm for treating ADHD***
- ***To more efficiently promote learning, neurofeedback professionals commonly schedule treatment sessions two or more times per week, particularly during the initial 10 to 20 sessions***
- ***While the costs of neurofeedback are front-loaded and therefore initially greater compared to traditional psychotherapy and/or the prescribing of ADHD medications, the actual costs are comparable or less when viewed over time***

Neurofeedback (NFB), also known as EEG Biofeedback, is a treatment modality for ADHD that is based on the behavioral processes of operant conditioning and learning theory. By definition NFB is a type of behavior therapy and therefore should be considered a subtype of psychotherapy. There has been confusion in the research literature about how to characterize NFB, but there is no question that it is a form of Behavior Therapy, even though it uses specialized technology to directly measure and report brain functioning, i.e., EEG waves, and use these measures to guide treatment. Unlike standard electroencephalography, NFB utilizes modern EEG signal digitizing processes to enable rapid EEG recording and quantification for mathematical manipulation and virtually instantaneous feedback to the patient. The term *quantitative EEG* (qEEG) refers to both the digitized EEG recording process as well as to the assessment product of this process, sometimes also called a "brainmap."

NFB feeds information on a patient's EEG activity back to them in various forms via a computer screen and speakers. Using this feedback loop, an individual's brain is able to gradually make needed changes to itself over time through practice during NFB sessions. Feedback usually consists of auditory &/or visual rewards, and in some cases tactile feedback. These rewards are delivered when the measured brainwave activity meets a predetermined level for a specified length of time. Because receiving rewards is pleasant, the individual undergoing NFB training seeks to repeat the experience. Rewarding experiences lead to the release of neuromodulators (such as dopamine) that influence structural plasticity within the brain – so with sufficient repetition, the circuits and pathways whose activation leads to the reward are reinforced. As the individual starts to master the current level of difficulty, the therapist gradually increases the level of difficulty in order to continue challenging the brain away from

its formerly dysregulated state, and thus shape the brainwave activity towards higher levels of functioning and self-regulation.

NFB sessions typically last for 45 to 50 minutes. Active sensors (surface electrodes) are placed in predetermined location(s) on the scalp to record the brain's electrical activity. Reference and ground electrodes are generally placed on the ears, or other locations such as the mastoid, to complete the required electrical circuit. It is important to mention that no electrical current is introduced into the brain using NFB equipment. Decisions regarding placement of the active recording electrode(s) and which EEG frequencies to reinforce/suppress are determined by: 1) the quantitative electroencephalographic assessment (qEEG), 2) the association of symptoms to brain locations, and/or 3) protocols that have been shown effective in research studies with similarly diagnosed patients.

Typically, 30 to 40 NFB sessions are required to treat an ADHD case of average severity but the range is as low as 10 sessions to more than 40. Most clinicians report reaching maximum effect, including long-term maintenance, by 40 sessions. Treatment is usually completed in four to seven months when sessions are conducted a minimum of two times per week. Since two or more sessions may be done in a week, NFB differs from psychotherapy in which sessions are usually once a week. Typically, one NFB session per week does not provide enough practice opportunities to produce efficiently the improvements in brain self-regulation as do multiple sessions per week. This front-loading of sessions tends to make NFB treatment appear more expensive than psychotherapy; however, the cost for NFB is a concentrated cost over several months whereas the cost of psychotherapy is typically similar but spread out over many months or years. Therefore, NFB is usually a one-time intervention of 40 or fewer sessions over the course of four months or less, whereas psychotherapy and/or stimulant medications often will go on for several years. Very few if any individuals with ADHD will respond in five sessions or less to any form of treatment, including medications which are often prescribed for years. However, when NFB treatment is complete, there is a high probability of long-term maintenance of treatment gains, unlike what research has found with medication usage. The cost of NFB for a 10 year-old child typically ranges from \$3000 to \$4500 over a relatively short period of time compared to parent training and psychotherapy, plus continued medication usage for years, possibly into adulthood. Although medication costs vary, the long-term medication and medication-management costs alone for ADHD often exceed \$6,000. There is also the issue of quality of life, which is difficult to put a price on, but also includes the negative side effects that are common with stimulant medications.

There is no specific licensure for NFB professionals since it is considered a behavior therapy within the psychotherapeutic treatment modality, similar to cognitive behavioral therapy or other specialized types of psychotherapy. This places professional oversight for NFB practitioners under state licensing boards. So the same licensure Boards for Psychologists, Social Workers and various Masters prepared Counselors are what govern clinicians who perform or supervise NFB practitioners. There is, however, a separate certification process for national/international certification of NFB competency issued by the Biofeedback Certification International Alliance (BCIA). BCIA has developed rigorous standardized training requirements that include didactic coursework, supervised experience, and written examination. Certification criteria include holding an advanced degree in a health care profession, adherence to all relevant state licensure practice laws, and requirements for continuing education in

the ethical practice of NFB. But as with other forms of psychotherapy and behavior therapies, any appropriately licensed Mental Health professional is eligible for BCIA certification after completion of all training requirements in EEG Biofeedback. In addition ISNR, the international professional organization for NFB providers, researchers, and educators, has published in its *Journal of Neurotherapy* the organization's *Standards of Practice* which provide guidelines for best practices in NFB and qEEG.

NFB has a robust scientific research data base. NFB has been practiced for many decades, and hundreds of thousands of patients have benefited from it. Patients with a variety of diagnoses have seen clinical improvement, often after having failed other treatments. While this review is focused on evaluating the evidence base for treating ADHD, there is a growing research base supporting NFB's effectiveness in treating other behavioral health disorders including Depression, Substance Use Disorders, Anxiety Disorders, and more recently Autism.

A key advantage that NFB has in comparison to treatment as usual for the above disorders, whether psychosocial or medications, is the use of normative, standardized and quantifiable measures to track clinical progress and to help guide treatment decisions. For example, EEG data is constantly produced and is used along with symptom monitoring to plan and evaluate treatment progress and outcome, affording NFB a level of precision, personalization and accountability not available to other therapies. This consistent individual measurement and accountability is strengthened when the data is paired with standardized and quantifiable psychological testing and assessments such as computerized continuous performance tests (CPT) and behavioral rating scales used in treating ADHD. Many practitioners use a CPT and behavior rating scale as a benchmark prior to initiating NFB treatment and then retest several times over the course of treatment to help verify progress and change in targeted symptoms. Significant reductions in ADHD symptoms following NFB treatment have been documented through numerous published articles in peer reviewed scientific journals.

This routine tracking of treatment progress with standardized instruments and metrics is in stark contrast to the typical total absence, or at best sporadic, use of standardized monitoring by almost all other behavioral health clinicians. This type of quantification and measurement available in NFB treatment allows case management to be more precise than with other therapies, enabling treatment decisions to be based on an ongoing record of hard data.

## **The Inadequacy of Current ADHD Treatments**

### **Key Points:**

- ***Optimal versions of the commonly reimbursed treatments for ADHD, including stimulant medications, fail to result in sustained benefit for the majority of children as documented by the NIMH-funded MTA Cooperative study, the gold standard study in ADHD treatment effectiveness research***
- ***In the MTA study, free multi-component behavior therapy, at a cost of over \$10,000.00 per case, failed to result in any significant reduction in core ADHD symptoms beyond that achieved by subjects who were referred to community care***

- ***Even with optimal outpatient behavioral therapy and medication treatment, ADHD is an ongoing debilitating illness and the societal costs that are associated with its ineffective treatment include over 10% of children requiring psychiatric hospitalization one or more times during follow-up***
- ***More effective treatments for ADHD are desperately needed and such treatments warrant reimbursement by healthcare insurers to foster their wide implementation***

ADHD is the most frequently diagnosed pediatric behavioral health disorder in America with approximately 8% of children and youth meeting its diagnostic criteria.<sup>1-3</sup> Stimulant medication and behavior therapy are the two most widely accepted treatments for ADHD<sup>4</sup> and these treatments are commonly reimbursed by healthcare insurers. While both interventions have met the efficacy standards for evidence-based treatment and been recognized as such by professional societies including the American Academy of Child and Adolescent Psychiatry,<sup>5</sup> the results of the MTA Cooperative study raise concern as to the actual sustained benefit of these treatments, particularly behavior therapy, in treating the core symptoms of ADHD.

The NIMH-funded MTA Cooperative study is the largest and most expensive treatment effectiveness study for ADHD ever conducted. It was a ‘cooperative’ study in that it involved many of America’s most prominent researchers in the psychotropic and behavioral treatments for ADHD in the study’s design, oversight, analysis, and reporting of results. This multi-centered open-label trial randomly assigned 579 children with ADHD Combined Type to 14 months of systematic medication management (SMM), multi-component behavior therapy (BT), combined SMM/BT, and referral to community care (CC) to evaluate these interventions’ effectiveness.<sup>6</sup> Follow-up assessments were then conducted at 10 months,<sup>7,8</sup> 22 months,<sup>9</sup> and 4.83 and 6.83 years<sup>10</sup> after the end of study-directed treatment.

The SMM, BT, and combined SMM/BT interventions were designed by the leading experts in these treatments and took a ‘*spare-no-expense*’ approach to ensure that the children assigned to each group received optimal versions of the assigned care that is unlike what is obtainable in the vast majority of real-world treatment settings. Table 1 describes each intervention package.

The SMM intervention included daily changing each child’s medication between placebo and three different doses of Ritalin for the first 28 days of treatment in a blinded manner such that no one involved in the child’s care knew what he/she was taking each day. During this time, parents and teachers provided daily ratings of the child’s behavior and adverse side-effects. Expert clinicians then blindly reviewed graphs of this data to select as the child’s starting dose, the one that yielded optimal symptom reduction while minimizing side-effects. If the child did not obtain an adequate response to any of the 3 Ritalin doses, the treating pharmacotherapist then performed non-blinded trials of 3 or more additional medications while still evaluating the effectiveness of each trial based on parent and teacher ratings of the child’s responses to same. In addition to monthly office visits with the parents and child that included providing advice, support, and recommended articles and books on ADHD for the parents to read, the treating pharmacotherapist also had monthly phone calls with the child’s teachers and regularly readjusted medications throughout the 14 months if the child was not doing sufficiently well.



For the BT intervention, the researchers integrated into the school year a comprehensive package of behaviorally-based parent training,<sup>11</sup> child-focused BT,<sup>12</sup> and school-based BT<sup>13</sup> interventions that prior research had found evidence-based. A conservative estimate of the cost to provide such a comprehensive package of behavioral treatments is over \$10,000. Even for families who could afford it, such a comprehensive package of BT is simply not available in over 95% of American communities.

In order to optimize outcomes for those assigned to the combined SMM/BT intervention, the child, parents, and teachers received both sets of treatments provided in an integrated manner with information sharing and ongoing consultation between the behavioral psychologist/teacher-consultant and the pharmacotherapist. These clinicians followed a manual to determine if and when an adjustment in one treatment should be made first versus intervening with the other treatment. A conservative estimate of the cost to provide the integrated SMM/BT treatment is over \$16,000. Children/families in all of the study-directed treatments also received up to an additional 8 sessions as needed to address clinical emergencies and/or instances of possible dropout from the study. Furthermore, these children/families were provided with treatment recommendations and referrals for continuing care at the end of their 14 months of study-directed treatment.

As seen in table 1, the parents and teachers of children assigned to the SMM, BT, and SMM/BT experimental groups were extensively involved in the children's assigned treatment, especially those in the BT and SMM/BT groups, yet the study's primary outcomes were based on parents & teachers completing standardized rating scales of the child's behavior at baseline, 3 and 9 months into the study, and after 14 months of study-directed treatment. ***The use of non-blinded assessments by those who were involved in the study-directed treatments likely inflated the initial report of outcomes from said treatments particularly in comparison to those assigned to community care referral in which there was no systematic effort to involve parents and teachers in whatever (if any) care was provided.*** Despite this measurement bias that especially favored BT and SMM/BT; **BT failed to separate from community care**, and SMM/BT from SMM, on any direct comparison of the primary ADHD outcomes at the end of study-directed treatment and follow-up assessments. In secondary analyses, there was modest evidence that at the end of study-directed treatment (but not follow-up) the children in the integrated SMM/BT group did better overall than those receiving only SMM.

In the 10-month follow-up assessment, the effect size for SMM and SMM/BT's superiority over BT and community care was cut in half (.6 to .3), and at the 22-month, and 4.83 and 6.83 year, follow-up assessments there were no significant differences between the four experimental groups on any of the primary ADHD outcomes making it hard to argue that 14 months of comprehensive BT, either alone or in combination with SMM, conferred any sustained advantages to the children assigned to these interventions. ***Furthermore, the MTA authors report that "although the MTA data provided strong support for the acute reduction of symptoms with intensive medication management, these long-term follow-up data fail to provide support for long-term advantage of (continued) medication treatment beyond 2 years for the majority of children."***<sup>10</sup>

In the conclusion of the final follow-up article, the researchers' state, "*Our findings suggest that community treatments can improve ADHD symptoms and associated impairment, but even when preceded by intensive medication management and/or behavioral therapy for 14 months, continuing*

*community interventions are unable, on average, to "normalize" children with ADHD. These findings apply to a range of symptom and functioning indices including delinquency, arrests, grade retentions and letter grades earned in school, and psychiatric hospitalizations that occur for an important minority of the sample. Hence, there is a practical need to pursue further research to develop and deliver more effective sustainable interventions..."<sup>10</sup>*

The MTA Cooperative study results document that even when 'evidence-based' care is optimally delivered for 14 months and then followed for many years by ongoing community care, these treatments which are **commonly reimbursed by insurers** do not result in sufficient benefit for the majority of children diagnosed with ADHD. Given that at a cost of over \$10k per case, the evidence is that BT alone without stimulants had no measurable impact on ADHD's core symptoms beyond that obtained by referral to community care, and the at-best modest near-term benefit from comprehensive SMM/BT over SMM alone—**and no evidence of sustained benefit**—combined with the lack of evidence of sustained benefit for medication treatment beyond two years, new and more effective treatments for ADHD are desperately needed. This is particularly the case due to:

- The ongoing debilitating nature of ADHD and the societal costs that are associated with its ineffective treatment including over 10% of the children in the MTA study requiring psychiatric hospitalization one or more times during follow-up with those in the referral to community care group having the **fewest** such hospitalizations (**BT: 12.3%**; SM/BT: 10.4%; SMM: 10.4%; **Referral to Community Care: 8.3%**);
- The fact that many children do not respond adequately to ADHD medications and/or have significant adverse side-effects from them; and
- Growing parental and professional concerns about medicating children for ADHD due to uncertainty about the long-term risks and benefits of these medications.

## **Neurofeedback: The Operant Conditioning of Trainees' EEG\*\*\***

### **Key Points:**

- ***The foundation of neurofeedback is animal and human research combining operant conditioning and neuroscience. This research has resulted in neurofeedback becoming widely recognized as an evidence-based treatment for epileptic seizure disorders***
- ***When laboratory animals are provided with real-time measurements of neuronal electrical activity they can learn to control that activity via operant conditioning***
- ***EEG is a non-invasive technology and provides real-time measurement of changes in neuronal electrical activity***
- ***When healthy adult trainees are provided with real-time EEG feedback, they can learn to regulate the targeted neuronal electrical activity via operant conditioning with resulting improvements in associated outcome domains***
- ***We now have over 40 years of published research in both animals and humans demonstrating that neurofeedback is effective in teaching subjects to regulate the targeted neuronal electrical activity with resulting improvements in associated behaviors***

Animal research from the early 1960s demonstrated that decreases in motor activity were associated with increased 12-16hz electrical activity in the sensorimotor cortex;<sup>14,15</sup> an activity pattern Stermann and Wyrwicka named the sensorimotor rhythm (SMR).<sup>16</sup> They found that when hungry cats were feed contingent upon the occurrence of SMR, the cats “became very alert” and displayed “an almost intense cessation of movement.”<sup>16</sup> In subsequent studies, Stermann and colleagues demonstrated that cats learned to increase SMR when contingently reinforced for it<sup>17</sup> and that following SMR training cats became more resistant to drug-induced seizures.<sup>18</sup> This line of research has resulted in neurofeedback (NFB) training being widely recognized as an evidence-based treatment for seizure disorders.

More recent studies published in leading scientific journals have demonstrated that monkeys can learn via operant conditioning to increase or decrease targeted electrical activity in whole networks of neurons resulting in changed behavior as well as long-lasting changes in neuronal functioning (see table 2). For example, Shafer and Moore recently published in the journal *Science* a study demonstrating that monkeys trained to alter the electrical activity of neurons associated with visual processing exhibited enhanced visual perception following NFB training.<sup>19</sup> ***Importantly, because these subjects are laboratory animals, placebo effects are not a factor in accounting for the resulting performance enhancement.***

From the very earliest EEG recordings carried out by Hans Berger in 1924,<sup>20</sup> researchers noticed that human brain activity is rhythmic and that the frequency of these rhythms tend to be associated with different mental states. These distinct rhythmic frequencies were given different names: delta, theta, alpha, beta, gamma, and SMR. Starting in the 1960’s, researchers began experimenting with allowing subjects to “watch” their own brain activity in real-time as it was being recorded while encouraging them to increase selected frequencies. These early studies demonstrated that just as with cats and monkeys, humans can learn to modify all of the EEG rhythms that are present during wakefulness, namely, theta,<sup>21,22</sup> alpha,<sup>23,24</sup> SMR,<sup>25,26</sup> beta,<sup>27,28</sup> and gamma.<sup>29</sup> These pioneering studies demonstrated that, through operant conditioning and the use of non-invasive EEG measurement, humans can learn to modify many aspects of their brains’ electrical activity with corresponding changes in behavior. Furthermore, controlled studies with normal adults have shown that (see table 3):

- NFB training leads to significant changes in the way the brain functions during tests of cognitive ability<sup>30-32</sup>
- These NFB-induced changes in brain functioning are associated with improved performance on tasks requiring
  - sustained attention,<sup>30,31,33-35</sup>
  - altered visual processing in a way suggesting increased mental flexibility;<sup>29,36</sup>
  - language-based information processing,<sup>37,38</sup> and
  - working and longer term memory<sup>29,33,36</sup>
- When comparing two or more distinct NFB protocols within a single study, the performance gains obtained with each protocol are not identical supporting the hypothesis that the improved performance is linked to the particular pattern of brain activity practiced during NFB training versus the result of placebo effects or other extraneous factors.<sup>29-31,33,36</sup>

NFB training can also have very specific and circumscribed effects depending on the brain region that is trained. For example, in humans, the majority of language processing takes place in the perisylvian cortex. When subjects learned to modify activity in this region through NFB training, their ability to make lexical decisions on a word recognition test improved compared to the control condition.<sup>37,38</sup> However, this training did not alter their performance when asked to push a button in response to a flashing light, indicating that training did not alter general visual perception, sensory processing, or reaction time.

A key observation that has emerged from research with healthy adults is that not everyone who receives NFB training using current methodologies learns how to modulate their brain activity. The number of these “non-responders” to NFB decreases as the training period is lengthened. For example, during NFB training that took place on a single day, half of the subjects learned to modulate their brain activity.<sup>32</sup> When NFB training continued for several weeks, approximately 50-80% of individuals successfully learned to modulate their brain activity.<sup>35,37-39</sup> When examining performance on tests of attention, working memory, cognition, &/or other aspects of executive functioning, the most dramatic performance gains are consistently observed in those individuals who were most successful at modifying the targeted brain activity during their NFB training sessions.<sup>30,32,35-39</sup> Similarly, in NFB studies that included tests linked to overall intelligence, individual gains were correlated with success at learning to modify the targeted brain activity.<sup>29,32,39</sup> In other words, individuals who “respond” to NFB training by learning to control the targeted brain activity are the ones who benefit while those who do not learn to control the targeted brain activity typically do not significantly improve on the outcome measures. ***This consistent finding across studies strongly suggests that it is the successful operant conditioning of a particular pattern of the targeted brain activity via NFB that is responsible for improved performance and not due to placebo effects or other extraneous factors.***

## Neurofeedback: An Evidence-Based Treatment for ADHD

### Key Points:

- ***Neurofeedback to treat ADHD is built on basic neuroscience research demonstrating that cats can learn, via operant conditioning, to increase their sensory motor rhythm resulting in behavioral changes such as them becoming physically calm while still highly alert***
- ***The first neurofeedback study to treat ADHD was seminal and used a reversal design to demonstrate that when neurofeedback was used to reinforce the sensory motor rhythm the children’s core ADHD symptoms decreased and when neurofeedback was used to suppress this EEG rhythm the children’s symptoms increased***
- ***It can be argued that neurofeedback’s scientific foundation is as good or even superior to psychopharmacology research in which each of its major medication classes were discovered by accident in the 1950s and 60s. Multiple NIMH-funded comparative effectiveness studies have now demonstrated that despite billions of dollars spent in research, the outcomes from psychotropic drug treatment while helpful to millions of people during the acute phases of these illnesses have not produced the long-term positive outcomes that everyone had hoped for***

- ***Randomized controlled trials have found neurofeedback to be equivalent to stimulant medication—and superior to EMG biofeedback, computerized cognitive training, and cognitive behavioral training—in treating the core symptoms of ADHD. Given this research data and the fact that many parents, patients, health professionals and teachers are desperately looking for alternatives to stimulant medications, it is surprising that more insurers do not reimburse for NFB treatment***
- ***In five studies neurofeedback has been found to result in sustained benefits when reassessed even up to two years after the end of treatment and these findings are in stark contrast to the lack of sustained benefit from either behavior therapy or stimulant medication as documented in the MTA Cooperative study***
- ***A 2009 meta-analysis of neurofeedback involving 1,194 ADHD subjects concluded that neurofeedback meet the highest level of evidence-based support for the treatment of ADHD “with a large effect size for inattention and impulsivity and a medium effective size for hyperactivity”***
- ***A recent meta-analysis comparing seven non-pharmacological treatments for ADHD found that neurofeedback was more than twice as effective as the other treatments with an average weighted effect size of .21 compared to effect sizes of only .09 or less for each of the other six behaviorally-based treatments and this analysis did not even include four rigorously controlled NFB studies because they were published after cut-off date for inclusion***
- ***In October 2012, the company that maintains the American Academy of Pediatrics’ ranking of research support for child and adolescent non-pharmacological treatments, elevated neurofeedback to the highest level of evidence-based support for the treatment of ADHD***

***NFB is an evidence-based treatment for ADHD that has been built on the combination of basic neuroscience research and operant conditioning thanks to the pioneering efforts of neuroscientists such as Maurice Serman and Joel Lubar.*** Building on Serman’s research, in 1976 Lubar published a study demonstrating SMR training’s effectiveness with 8 severely epileptic subjects,<sup>25</sup> one of whom was a boy with a co-occurring diagnosis of hyperkinetic syndrome (aka: ADHD) whose excess motor activity significantly decreased during treatment.<sup>40</sup> Due to the known effects from animal studies of the functional relationship between SMR training and motor inhibition, combined with this serendipitous finding, Lubar and Shouse conducted a study of SMR training with 4 boys diagnosed with hyperkinetic syndrome with no other comorbid disorders.<sup>41,42</sup> The study used a within subject reversal design to assess the impact of SMR training on ADHD’s core symptoms with both the subjects and raters blind to the experimental conditions thereby minimizing the possible role of extraneous factors on the observed outcomes. When NFB was used to increase SMR (reward **increased** 12-14 Hz & **decreased** 4-7Hz over the sensory motor cortex), the rate of SMR increased and the subjects’ core ADHD symptoms decreased. These improvements were reversed during the counterconditioning phase when NFB was used to decrease SMR (reward **decreased** 12-14 Hz & **increased** 4-7Hz) with the subjects’ rate of SMR decreasing and ADHD symptoms increasing. The improvement in core ADHD symptoms returned when SMR training was reintroduced and these gains in classroom behavior were maintained when Ritalin was withdrawn in the final phase of the study (see table 4).

The Lubar and Shouse study would never be authorized today by an institutional review board due to the SMR counterconditioning/reversal phase. Yet it is the inclusion of the counterconditioning phase

that gives strong support to the conclusion that the hypothesized mechanism-of-action (increased SMR) was responsible for the observed positive changes in core ADHD symptoms. Similar to the NFB studies with healthy adults, this study found that 1) the two NFB protocols (reward increases in SMR versus decreases in SMR) had clear differential effects on the subjects and 2) not all subjects learned to modulate SMR and the one subject who did not learn failed to improve.

The Lubar and Shouse study is seminal in the evolution of NFB as an evidence-based treatment for ADHD and analogous to a hypothetical psychopharmacology comparator trial in which the chemical structure of two pills are the opposite of each other and when studied in a blinded trial 1) they have opposite effects on the targeted area of neuronal functioning and 2) the hypothesized opposite effects in observable/real-world behavior occur. Psychopharmacological practice would be much further advanced today if only there were such studies in its history versus the plethora of placebo-controlled trials of me-too drugs.

In reviewing pharmacotherapy's current status, NIMH Director Dr. Thomas Insel recently noted that repeatedly in NIMH-funded comparative effectiveness studies second-generation psychotropic medications have been found to be no better than first-generation ones and despite the dramatic increased use of second-generation psychotropic medications stated that there is *"no evidence that the morbidity or mortality of mental disorders has dropped substantially in the past decades"* with these drugs having *"a combined market of \$25 billion"* in 2007 in the United States alone. Dr. Insel then goes on to state, ***"The unfortunate reality is that current medications help too few people to get better and very few people to get well."***<sup>43</sup>

As evidenced in a 2012 editorial by Dr. Christian Fibiger, former VP of Neuroscience at Eli Lilly, Insel is not alone in coming to this conclusion. Dr. Fibiger writes, *"Psychopharmacology is in crisis. The data are in, and it is clear that a massive experiment has failed: despite decades of research and billions of dollars invested, not a single mechanistically novel drug has reached the psychiatric market in more than 30 years. Indeed, despite enormous effort, the field has not been able to escape the "me too/me (questionably) better" straightjacket."*<sup>44</sup> Dr. Fibiger then goes on to note that each of psychiatry's major classes of medication were discovered by *"serendipitous clinical observation"* and likely would not have been discovered using current drug discovery strategies. In his conclusion Dr. Fibiger states, *"what the field has been doing for the past 3 or 4 decades has failed to generate effective, mechanistically novel psychopharmaceuticals... there is no choice but to make changes in how we approach the study of disease mechanisms, drug discovery, and development in psychiatry. This will require major investments in neuroscience research, humility in the face of our ignorance, and a willingness to consider fundamental reconceptualizations of psychiatry itself."*<sup>44</sup>

Building on the neuroscience research foundation provided by Maurice Serman and Joel Lubar, NFB's evidence-base continues to grow with over 50 peer-reviewed journal articles published to date documenting its effectiveness in treating ADHD's core symptoms.<sup>45</sup> In 2009, Arns and colleagues published the most complete meta-analysis to date of NFB's effectiveness in treating the core symptoms of ADHD.<sup>46</sup> This analysis had 1,194 ADHD subjects from 10 controlled studies combined with an additional five prospective pre/post design trials. Their analysis concluded that *"neurofeedback treatment for ADHD can be considered "Efficacious and Specific" (Level 5) with a large*

*effect size for inattention and impulsivity and a medium effective size for hyperactivity,”* the highest rating possible based on the criteria jointly accepted by the International Society of Neurofeedback and Research (ISNR) and the Association for Applied Psychophysiology and Biofeedback (AAPB) that were modeled on those established by the American Psychological Association (APA). Besides SMR training (increase SMR/decrease theta), this meta-analysis included studies using two other NFB protocols; theta/beta (decrease theta/increase beta) and operant conditioning of slow cortical potentials (SCP). As noted by Arns et al, both SCP and SMR neurofeedback have been successful in treating epilepsy<sup>47</sup> likely due to both methods teaching patients how to better regulate cortical excitability while controlled studies comparing SCP and theta/beta NFB show similar effects on the core symptoms of ADHD.<sup>48,49</sup>

For this paper, we reviewed in detail the controlled studies published during the past decade that evaluated NFB’s effectiveness in treating children with ADHD (see table 5). Summarizing across these studies that included 701 ADHD children and adolescents our review found:

- Similar to studies with healthy adults and Lubar/Shouse, not all ADHD children learned to regulate their EEG and it was those that learned to regulate best their EEG that had the greatest improvement in ADHD symptoms<sup>50-54</sup>
- In comparison to control groups, NFB resulted in significant improvements in
  - Parent-rated core symptoms of ADHD;<sup>48-62</sup>
  - Teacher-rated core symptoms of ADHD;<sup>48-56,61,63</sup>
  - Continuous performance tests of core ADHD symptoms;<sup>51/52; 55-59,61,63</sup>
  - Neuropsychological measures of response inhibition, reaction time, and concentration;<sup>54,59-61</sup> and
  - Neurophysiologic measures of improvement relevant to ADHD including the QEEG Attention Index,<sup>55</sup> Event-Related Potentials (P300) during continuous performance testing,<sup>57</sup> and activation of regions in the brain related to attention and executive functioning using fMRI<sup>59</sup>
- NFB was significantly superior to sham NFB,<sup>51/52</sup> EMG biofeedback,<sup>61</sup> computerized cognitive training,<sup>48,60</sup> cognitive behavioral training,<sup>54</sup> and waitlist control<sup>57,59,63</sup> in improving outcome measures of ADHD’s core symptoms
- NFB training resulted in improvements equivalent to those achieved by stimulant medication.<sup>56,58</sup> While the Rossiter and Fuchs et al studies relied on patient/parental preference versus randomization to determine treatment group assignment, this reflects real-world practice and thereby strengthens the relevance of the results to insurers and parents
- In a large randomized controlled trial, NFB resulted in improvements equivalent to those achieved by stimulant medication alone as well as medication in combination with NFB<sup>62</sup>
- When assessed, NFB resulted in changes in EEG consistent with the NFB protocol that was trained<sup>49-53,55,61</sup> and these EEG changes persisted when reassessed at 6 months<sup>49</sup> and 2 years after the termination of treatment<sup>65</sup>
- In follow-up studies, NFB resulted in significant improvement in core ADHD symptoms that were sustained when reassessed at six months<sup>49,53,64</sup> and 2 years<sup>65,66</sup> after treatment termination

In addition to our review of the evidence, a 2012 meta-analysis published in the *Journal of Attention Disorders* found NFB to be **more than twice as effective** in treating the core symptoms of ADHD with an average weighted effect size of .21 compared to effect sizes of only .09 or less for the other six treatments with working memory training, behavior modification, school-based behavior therapy, behaviorally-based parent training, and behavioral self-monitoring treatments having negative effect sizes compared to the control group conditions. The negative effect size findings prompted the authors to conclude that these five commonly-utilized—and often insurance reimbursed—treatments for ADHD **“cannot be deemed to be efficacious.”**<sup>67</sup> This analysis did not even include four rigorously controlled NFB studies, each finding NFB to be a highly effective treatment for ADHD and involving a total of 301 ADHD child and adolescent subjects, because these studies were published after the cut-off date for study inclusion (see table 5).<sup>48, 60-62</sup>

Furthermore in October 2012, PracticeWise, the company that maintains the American Academy of Pediatrics’ ranking of research support for child and adolescent psychosocial treatments, awarded biofeedback/neurofeedback the **highest level of evidence-based support** for the treatment of ADHD.<sup>68</sup> Similar to those of ISNR and AAPB, PracticeWise’s rigorous ranking system is modeled on APA’s 5-level system for grading the strength of the evidence in support of mental health treatments for different diagnoses. PracticeWise has applied its ranking methodology to over 600 randomized controlled trials (RCTs) of psychosocial treatments. All of the biofeedback and neurofeedback RCTs reviewed by PracticeWise in arriving at NFB’s highest ranking were coded by three independent raters on variables related to the quality and relevance of the research including the number of RCTs and the resulting effect size of the biofeedback/neurofeedback treatments as compared to the experimental control group conditions. While the bulk of the RCTs reviewed by PracticeWise evaluated the efficacy of EEG neurofeedback, several EMG biofeedback studies for ADHD from the 1980s were also included.

## **A Balanced Approach to Rating the Evidence of NFB as a Treatment for ADHD**

### **Key Points:**

- ***Recent meta-analyses have shown a high level of agreement in the findings of open clinical trials and randomized controlled ones providing support for the position that a balanced approach to assessing a treatment’s evidence-base should take into account both forms of evidence***
- ***The ADHD treatment guidelines developed by the American Academy of Child and Adolescent Psychiatry takes such a balanced approach by rating ADHD treatments based on the preponderance of the evidence as to whether “the benefits of the recommended approach clearly exceed the harms of that approach”***
- ***Using this professional academy’s preponderance of the evidence evaluative standard, neurofeedback for the treatment of children and adolescents with ADHD clearly warrants the highest level of recommendation***

While many of the 50+ articles documenting NFB’s effectiveness in treating ADHD are reports of open clinical trials and inadequately-controlled ones, meta-analyses comparing open clinical trials to randomized controlled ones reveal that the results from the two approaches are highly concordant as



they are in the Arns et al meta-analysis and our review.<sup>69,70</sup> For example, in the *New England Journal of Medicine* Benson and Hartz analyzed the data from 136 published effectiveness studies of 19 different medical treatments and concluded, “In only two of the 19 analyses of treatment effects did the combined magnitude of the effect from the observational studies lie outside the 95% confidence interval for the combined magnitude in the randomized controlled trials.”<sup>69</sup> These findings strongly argue that a balanced approach to assessing a treatment’s evidence-base should take into account the results from open clinical trials as well as randomized ones and calls into question the empirical basis for only accepting as adequate findings from controlled trials.

This more balanced approach is reflected in the model used by the American Academy of Child and Adolescent Psychiatry (AACAP) committee in arriving at their ADHD treatment guidelines.<sup>5</sup> While we strongly disagree with AACAP’s placement of “*electroencephalographic biofeedback*” in the category of “*Areas for Future Research*” as **there is no evidence that they conducted their own review** of the NFB research to arrive at this decision, we do agree with their criteria for rating ADHD treatments based on the preponderance of the evidence as to whether “*the benefits of the recommended approach clearly exceed the harms of that approach*” (see figure 1).

**Figure 1**  
**AACAP’s Treatment Guideline Chart**

Evidence Quality	Preponderance of Benefit or Harm	Balance of Benefit and Harm
A. Well-designed RCTs or diagnostic studies on relevant population	Strong recommendation	Option
B. RCTs or diagnostic studies with minor limitations; overwhelmingly consistent evidence from observational studies	Recommendation	
C. Observational studies (case-control and cohort design)		
D. Expert opinion, case reports, reasoning from first principles	Option	No Rec
X. Exceptional situations in which validating studies cannot be performed and there is a clear preponderance of benefit or harm	Strong recommendation	
	Recommendation	

Using the above chart for guidance, NFB for the treatment ADHD clearly warrants the highest recommendation level for both children and adolescents due to:

- There are overwhelmingly consistent reports in observational studies during the past 35+ years of NFB’s effectiveness in treating ADHD’s core symptoms in children and adolescents and unlike stimulant medications, there have been no reports in the published literature of any adverse side-effects when using SMR, theta/beta, or SCP training to treat ADHD. This combination alone of consistent published reports of significant benefits without any recorded adverse side-effects makes NFB warrant the highest recommendation level for both children and adolescents.

- There are multiple RCTs with minor study limitations finding NFB to be an effective treatment of ADHD in children<sup>49,54,59-61,63</sup> and again, given the highly positive benefit/risk ratio warrants the strong recommendation rating for children.
- There are several well-designed RCTs with large numbers of subjects<sup>48,51/52,62</sup> along with the Arns et al.<sup>46</sup> and Hodgson et al<sup>67</sup> meta-analyses finding NFB is an effective treatment of ADHD's core symptoms in children. The Duric et al<sup>62</sup> RCT and the Arns et al. meta-analysis included adolescents as well therefore warranting the strong recommendation rating for both children and adolescents.

While not captured as criteria in AACAP's chart for arriving at guidelines, there are five studies in this review that assessed whether or not NFB resulted in sustained benefits after treatment ended,<sup>49,53,64-66</sup> including two studies with 2-year follow-up assessments.<sup>65,66</sup> ***In each of these follow-up assessments, the gains from NFB were maintained after treatment had ended and in one study had increased further in the 2-year follow-up assessment.***<sup>66</sup> In contrast, stimulant medications' beneficial effects are known to quickly cease when stopped, and in the MTA study the authors report that they found no evidence to support the "long-term advantage of (continued) medication treatment beyond 2 years for the majority of children." It is this apparent loss of efficacy in ADHD medication treatment that likely accounts for at least some of the dramatic increase in the prescribing of antipsychotic medications to children in recent years. In a new article published in *Archives of General Psychiatry*, Olfson et al.<sup>71</sup> report that in outpatient visits to psychiatrists and general practitioners between 1993-1998 and 2005-2009, the rate of antipsychotic medications prescribed to children increased by over 750% (from 0.24 to 1.83% of all visits). ***Their analysis found that disruptive behavior disorders (primarily ADHD) were the most common diagnoses in children that were prescribed an antipsychotic accounting for 63% of such cases, and that in 54.1% of the visits when an antipsychotic was prescribed to a child there was also an ADHD medication prescribed to the same child.***

Given the generally poor long-term outcomes for the most commonly utilized ADHD treatments, there is a desperate need for more effective interventions to be identified and strongly recommended by insurers and professional guideline committees for its treatment. Based on the combination of 1) the 35+ years of extensive basic and applied research documenting the efficacy of NFB in treating ADHD's core symptoms covered in this review including five studies demonstrating sustained benefit following treatment termination; 2) the recent Hodgson et al meta-analysis finding NFB to be more than twice as effective as the six other non-pharmacological ADHD treatments that were included in this analysis; and 3) PracticeWise's independent ranking for the American Academy of Pediatrics finding that NFB meets the highest evidentiary standards as an efficacious treatment for ADHD, ***NFB clearly warrants to be reimbursed by insurers for the treatment of ADHD in children and adolescents thereby facilitating its wide-spread adoption.***

**Appendix\*\*\***  
**Answering the Critics of Neurofeedback**  
By  
Ed Pigott, Ph.D.

In their 2005 review article titled “*Clinical Utility of EEG in Attention Deficit Hyperactivity Disorder*,” Drs. Sandra Loo and Russell Barkley, a widely recognized expert in ADHD, state that for EEG neurofeedback (NFB) to be considered a “*legitimate treatment*” it must not only be found effective but it also must be demonstrated in “*studies that are scientifically rigorous*” that:

- “*Changing the EEG is the mechanism of change in ADHD symptoms;*”
- The treatment effects must also “*generalize to non-treatment settings*” and “*persist over time;*” and furthermore
- “*Even with such demonstrations, it must also be shown that treatment is cost effective in managing the symptoms of ADHD relative to the prevailing empirically supported approaches.*”<sup>73</sup>

Logically, if we accept Loo/Barkley’s evidentiary standards for NFB, the same standards should be applied even-handedly to all psychological and pharmaceutical treatments for ADHD. Call it the “*What is good for the Goose is good for the Gander*” rule. A rule that is critical to ensure adherence to and thereby minimize bias when evaluating the evidence base of different treatments. By applying this rule, there are simply no psychosocial **OR** pharmaceutical treatments for any behavioral health disorder that meet the Loo/Barkley evidentiary standards as documented by “*scientifically rigorous*” research.

Dr. Barkley himself flagrantly violates his own “*treatment legitimacy*” standards. Though Barkley has been a strong proponent of stimulant medications to treat ADHD ever since completing his dissertation on this topic in 1976/77; despite billions of dollars spent in “*scientifically rigorous*” research efforts over the past 40+ years, we still do not know what are the mechanisms of change from stimulants that account for the observed improvements in ADHD symptoms as compared to a placebo in randomized trials typically lasting only 10 weeks or less.

In the Physician Desk Reference, every psychoactive medication has a statement similar to “*presumably works by*” or “*is thought to...*” when describing an FDA-approved drug’s hypothesized “*mechanism of change*” yet Barkley fails to hold stimulants to the same evidentiary standard that he asserts is necessary for NFB to meet before it can be considered a legitimate treatment. Take methylphenidate for example, the most commonly prescribed drug for ADHD:

“The mode of therapeutic action in humans is not completely understood, but methylphenidate ***presumably*** activates the brain stem arousal system and cortex to produce its stimulant effect. Methylphenidate ***is thought to*** block the reuptake of norepinephrine and dopamine into the presynaptic neuron and increase the release of these monoamines into the extraneuronal space. ***There is neither specific evidence which clearly establishes the mechanism whereby***

**Methylin produces its mental and behavioral effects in children, nor conclusive evidence regarding how these effects relate to the condition of the central nervous system.**<sup>74</sup>

Furthermore, it is well-known that the effects of stimulant medications do not “*persist over time*” when treatment is stopped as Barkley himself emphasizes on his website and this form of treatment is actually quite expensive given the fact that to maintain effectiveness people have to take medication on an ongoing basis, and for many, at ever higher doses &/or with intermittent medication changes and new drug augmentation due to the tolerance effects that commonly develop to the originally prescribed medication.

The combination of open-ended treatment by medication(s) and the associated physician fees for overseeing the prescribing of these drugs makes this form treatment very expensive with a poor cost-benefit return on investment as demonstrated by the MTA study authors’ own conclusion that they found ***no evidence*** to support the “*long-term advantage of (continued) medication treatment beyond 2 years for the majority of children*” ...and remember, this two-year outcome time-frame included the initial 14 months of optimal systematic medication management that was followed by referral for ongoing medication oversight by community-based physicians.

On the behavior therapy front, behaviorally-based parent training of the type developed by Barkley<sup>75</sup> (and included as one-leg of the multi-component behavior therapy treatment used in the MTA Cooperative study) and classroom management strategies have not been subjected to rigorous controlled trials in which the specific aspects of the interventions were shown to be the mediating mechanisms of change and that the observed changes generalized to other settings and persisted over time. ***In fact, we know that the effects of such behavioral strategies for ADHD do not generalize to other settings nor persist over time, as Barkley himself acknowledges on his website stating that:***

“Psychological treatments, such as behavior modification in the classroom and parent training in child behavior management methods, have been shown to produce ***short-term benefits*** in these settings. However, the improvements which they render are often limited to those settings in which treatment is occurring and ***do not generalize to other settings*** that are not included in the management program. ***Moreover, recent studies suggest, as with the medications discussed above, that the gains obtained during treatment may not last once treatment has been terminated.*** Thus, it appears that treatments for ADHD must often be combined and must be maintained over long periods of time so as to sustain the initial treatment effects. In this regard, ***ADHD should be viewed like any other chronic medical condition that requires ongoing treatment for its effective management but whose treatments do not rid the individual of the disorder.***<sup>76</sup>

The Loo/Barkley review article holds NFB to far higher evidentiary standards than they apply to their preferred “*legitimate treatments*” of stimulant medication and traditional behaviorally-based therapies reflecting profound bias on their part and thereby makes it hard to take as credible their selective review of the NFB research. ***The irony here though is that NFB comes far closer to meeting the Loo/Barkley evidentiary standards for the effective treatment of ADHD than either of their preferred treatments.*** Consider for example:

- The very first NFB studies for the treatment of ADHD published in 1976, 1977, & 1979 by Lubar and colleagues<sup>40-42</sup> demonstrated that *“changing the EEG is the mechanism of change in ADHD symptoms”* (see table 4). Using a reversal research design in which both the child subjects and raters of classroom behavior were blind to the experimental condition and the children acted as their own experimental controls, these N-of-1 studies found that 1) when NFB was used to reinforce the increase in SMR neuronal electrical activity the children’s rate of SMR activity increased while their core ADHD symptoms of inattentiveness, impulsivity, and hyperactivity decreased, 2) when NFB was used to reinforce the suppression of this EEG rhythm, SMR activity decreased and the children’s ADHD symptoms increased, and 3) when NFB was reintroduced to reinforce the increase in SMR, there was again both an increase in SMR activity along with a significant decrease in the children’s ADHD symptoms, ***thereby demonstrating with a high degree of certitude that “changing the EEG” via NFB was the mechanism of change in the children’s ADHD symptoms.*** To my knowledge, there are simply no analogous psychopharmacology comparator trials in which the chemical structure of two pills are the exact opposite of each other and when studied in a blinded trial 1) they have opposite effects on the targeted area of neuronal functioning and 2) the hypothesized opposite effects in observable/real-world behavior were found to have occurred. This is what was demonstrated in the Lubar et al studies and is the foundation on which subsequent NFB research is based. Unfortunately from an ease-of-scientific-confirmation perspective, such reversal design studies would never be authorized by an Institutional Review Board these past several decades due to the known negative effects of suppressing SMR neuronal electrical activity in children with ADHD which includes an increased risk of seizures in addition to the worsening of their core ADHD symptoms as occurred in the Lubar et al N-of-1 studies.
- In addition to the Lubar et al studies, there are now seven new ones published during the past decade demonstrating that NFB resulted in treatment protocol-specified *“changes in the EEG”*<sup>49-55,61</sup> and these improvements in EEG self-regulation persisted when reassessed at 6 months<sup>49</sup> and 2 years after the termination of treatment<sup>65</sup> with associated sustained improvement in ADHD core symptoms. Furthermore in the four studies that correlated the extent of changes in subjects’ EEG to ADHD symptom improvement, those subjects who were most successful in learning to self-regulate their EEG had the greatest improvement in ADHD symptoms<sup>50-54</sup> ***thereby providing additional strong evidence that “changing the EEG is the mechanism of change in ADHD symptoms” resulting from NFB treatment.***
- In comparison to control group conditions, NFB has been shown to result in significant improvements in 1) parent-rated core symptoms of ADHD;<sup>48-62</sup> 2) teacher-rated core symptoms of ADHD;<sup>48-56,61,63</sup> 3) continuous performance tests of core ADHD symptoms;<sup>51/52; 55-59,61,63</sup> 4) neuropsychological measures of response inhibition, reaction time, and concentration;<sup>54,59-61</sup> and 5) neurophysiologic measures of improvement relevant to ADHD including the QEEG Attention Index,<sup>55</sup> Event-Related Potentials (P300) during continuous performance testing,<sup>57</sup> and activation of regions in the brain related to attention and executive functioning when assessed using fMRI.<sup>59</sup> These findings from numerous international research groups ***provides strong evidence that unlike traditional behavior therapy, the gains from NFB treatment “generalize to non-treatment settings” and this generalization effect is most likely due to the***

**subjects' learning how to self-regulate their EEG thereby promoting the wide generalization of treatment effects.**

- In five follow-up studies published during the past decade, NFB resulted in significant improvement in core ADHD symptoms that were sustained when reassessed at six months<sup>49,53,64</sup> and 2 years<sup>65,66</sup> after treatment termination **thereby providing strong evidence that unlike stimulant medications and traditional behavior therapy the gains from NFB treatment “persist over time” following treatment termination.**

In contrast to Dr. Barkley's acknowledgement of the limited effectiveness for what are the widely deemed the “*legitimate treatments*,” those being open-ended medication(s) and behavioral management programs that are implemented across settings, such that “**ADHD should be viewed like any other chronic medical condition that requires ongoing (combination) treatment(s) for its effective management but whose treatments do not rid the individual of the disorder**,” the Gani et al study found at the two-year follow-up assessment of NFB's effectiveness 1) “**yet another significant reduction of number of (ADHD-related) problems and significant improvement in attention was observed**,” 2) “**EEG-self regulation skills were preserved**,” 3) “**half of the children no longer met ADHD criteria**,” and 4) “**only 22% were still taking medication for ADHD**.” These authors therefore concluded that, “**Neurofeedback appears to be an alternative or complement to traditional treatments. The stability of changes might be explained by normalizing of brain functions that are responsible for inhibitory control, impulsivity and hyperactivity.**”<sup>66</sup>

In Dr. Barkley's world of legitimate treatments, there's the need for a lifetime of his preferred ones yet even they “*do not rid the individual of the disorder*” while in the Gani two-year follow-up assessment of the illegitimate NFB, **half of the children no longer met the criteria for being diagnosed with ADHD** and as these authors note, “**in contrast to the results of the MTA Cooperative study, in our study children still improved although treatment was terminated 2 years ago.**”<sup>66</sup>

## **Is the Double-Blind Placebo-Controlled Research Design Appropriate for Neurofeedback?**

The most common criticism of NFB research by Loo/Barkley and other reviewers<sup>77-80</sup> is that it has not been demonstrated as effective in placebo-controlled trials in which the NFB clinicians, child subjects, and parents, teachers, and other outcome raters are blind to whether or not the subjects were receiving actual EEG or sham feedback. The results in the few ADHD studies that have followed this methodology have been equivocal. The largest study with an N of 53 subjects demonstrated clear superiority of actual EEG feedback over sham feedback.<sup>52</sup> The two other small studies, each explicitly designed as ‘feasibility’ trials, found no differences in outcomes between EEG versus sham feedback due to the significant improvements in ADHD symptoms for both groups when these symptoms were reassessed over the course of the study.<sup>81,82</sup> **Seven points:**

**First**, similar to Loo/Barkley the authors of these reviews do not apply the same research criteria when evaluating the effectiveness of their own preferred treatments. For example Dr. Nicholas Lofthouse, an assistant professor at Ohio State University (OSU) and the lead author in three of these reviews,<sup>77-79</sup>

identifies behavior therapy and cognitive behavioral therapy (CBT) as being evidence-based treatments for ADHD (and in each of his reviews, NFB failed to achieve this designation)<sup>77</sup> yet neither of these treatments have ever been shown to be effective in placebo-controlled studies in which the treating clinician was blind to the experimental condition. In fact, it is widely recognized that these learning-based treatments are not suitable for such research designs (& in fact, such designs have therefore never even been attempted) because it is impossible to blind the clinician to the treatment condition. In research on learning-based treatments, the clinician follows behaviorally-based treatment procedures to optimize the targeted skills for learning and this cannot be done using **blind** clinicians. The same is true for NFB since it is the operant conditioning of the EEG and requires a trained clinician to maximize the learning effect by monitoring and ensuring that the desired brainwave pattern is in fact being reinforced. NFB is not analogous to a pill in which one can evaluate its effectiveness by simply comparing it to an inert/sugar pill version of it. NFB is a learning-based treatment and like other forms of behavior therapy requires oversight by a skilled clinician to ensure that the desired brainwave pattern is in fact being learned.

**Second**, attempts to blind the clinicians who are overseeing NFB training typically involve the use of computerized auto-thresholding software. This is the blinding strategy that Dr. Lofthouse and his OSU colleagues used in an NIMH-funded double-blind placebo-controlled feasibility study. The study used a NFB device called SmartBrain in which the responsiveness (typically speed & steering control) of the videogame controller was contingent on the child's EEG theta–beta power ratio falling "**below a threshold that was set minute-to-minute by fuzzy logic based on the immediately preceding EEG.**"<sup>82</sup> By using the SmartBrain device, the researchers could blind the clinician to the experimental condition since "*it did not require a 'NF coach' to guide trainees.*" Unfortunately, none of the nine study authors had any prior NFB expertise as evidenced in their biographies at the end of the article, and therefore were not aware that NFB's leading experts consider the use such of "auto-thresholding" technology as violating the most basic principles of learning on which NFB is based. In an article co-authored by Professors Serman and Lubar along with other experts titled, "**Neurofeedback and Basic Learning Theory: Implications for Research and Practice**" they write in regards to the use of auto-thresholding:

***"If the learner begins to fatigue, lose interest, or even stop actively participating in the training, the reward signals continue to be provided irrespective of whether they are producing the desired behavior. They are, in fact, being rewarded for only changing the (EEG) behavior based on the previous averaged time period, which may not be an actual change from the starting behavior point. Even worse, it may actually be in the opposite direction than the desired training parameter. Consider if the learner is being asked to reduce the amplitude of a given frequency band (as was the case in the OSU study) and the threshold is calculated automatically, they will always be getting a percentage of feedback even if the amplitudes are rising across time. If this occurs, at best, the learner may show improvements only if they continually demonstrate change in the desired direction. It is possible that they may show no learning and no effect...at worst they could effectively train in the opposite direction and result in an increase in aberrant and negative (EEG) behaviors....Finally as described earlier, the auto-thresholding procedure precludes the possibility of the neurofeedback being applied in a 'blinded' fashion. When investigating in a double-blind fashion, one has to resort to techniques like 'auto-thresholding' to force the blinded methodology impractically upon the***

neurofeedback intervention. ***This will contribute to null findings, as one of the primary components of the neurofeedback training is based in the learning principle of shaping that is completely violated in the auto-thresholding procedure.***<sup>83</sup>

Furthermore, in regards to the use of videogames for NFB training, such as those used in the OSU study, these experts write:

“Complex games offered in some products are contraindicated, given that the level of continuous feedback does not allow for a PRS (post-reinforcement synchronization) complex to occur because it is too difficult for the learner to extract meaningful information. Operant learning involves the formation of a response–reinforcer association. Complex games are much more likely to ‘overshadow’ the response–reinforcer association by the formation of a more salient stimulus–reinforcer association. ***This practically means they will associate the reinforcement with the stimulus rather than the desired specific brain behavior response...Therefore, in the application of neurofeedback, one ‘should stress exercise rather than entertainment’*** (Egner & Serman, 2006).<sup>84</sup> ***The reinforcement should lead to ‘knowledge of results.’ Therefore, it should specifically inform the learner whether the response was right or wrong and to what extent the brain signal changed.***<sup>83</sup>

The OSU researchers’ utter lack of NFB expertise resulted in them selecting for use in their study 1) a method for blinding the clinician (auto-thresholding) and 2) continuous-play videogame feedback which are rejected by the leading scientists in the field since these methodologies violate the most basic principles of operant conditioning on which NFB is based. The OSU researchers’ use of these methods significantly undermines any conclusions that can be derived from their ‘feasibility’ study.

**Third**, the OSU researchers deemed their study a success reporting that “*blinding appears to work, and sham does not prevent recruitment/retention*” and then go on to concluded that “*a large double-blind RCT is feasible and necessary to test specific NF effectiveness.*”<sup>82</sup>

This is a surprising conclusion on the authors’ part since even they acknowledged that their methods for providing NFB may have been significantly flawed when they state:

“The biggest limitation was the choice of NF technology, which used fuzzy logic to alter the reinforcement threshold from minute to minute, adapting the threshold to just-completed performance ***and not requiring focus on the NF training itself.*** Although this seemed like a good choice at the time...***most NF experts question its effect; they recommend manual changing of threshold and focusing on the EEG as a task*** (to be learned) ***rather than working indirectly through a videogame.***”

The OSU study demonstrated **NEITHER** that “*a large double-blind RCT is feasible*” **NOR** that such a study is “*necessary to test specific NF effectiveness.*”

To properly evaluate the authors’ claims regarding feasibility, it is critically important to remember the experimental conditions that were compared in this first-ever NIMH-funded study of NFB. In both



conditions, the ADHD children played videogames of their own choosing with the extent of their control in playing the games falling between the same two predefined percentages of the time (though not stated, with the SmartBrain device this is typically between 65 and 80%). The only apparent difference was whether the subjects' control was based on 1) their current EEG theta/beta ratio meeting a continuously fluctuating threshold determined by their "*immediately preceding EEG*" **OR** 2) randomly determined yet still always falling between the same percentages of time as the NFB group. For the children in both groups, they got to play their preferred videogames for 45 minutes, two to three times per week, **with essentially no differences** in the percent of time that they had full control over the game.

Given this study's methods, little wonder that there were no differential effects on child and parent satisfaction, blinding, study retention, and levels of reported ADHD symptom improvement—***all were exceptionally positive***. Of course they were all positive. For the children, there was little to complain about on the drive to the OSU clinic since regardless of group assignment they got to play their preferred videogames and only had to put up with short-lived intermittent interruptions in their ability to fully control the videogame. In fact, for those in the NFB group the most efficient cognitive strategy was to not continuously try to improve their theta/beta ratio since this only made it more difficult to sustain control when the threshold readjusted upwards—***either way, consistently trying or not they were 'rewarded' with having essentially the same level of control over the game***. Similarly, the same '*don't try just ignore the disruptions*' strategy was the most efficient one for those in the sham group as well. For both groups, the best that can be said of the OSU researchers' methodologies is that they likely taught the children equally well frustration tolerance skills so that the children could thereby better enjoy playing their preferred videogames.

For the parents, at no cost to themselves, their ADHD children went to a prestigious university clinic several times per week with few, if any, complaints and were participating in the first-ever NIMH funded study of NFB to treat ADHD. What was there not to like? The kids were happy and therefore the parents were happy and hopeful that this treatment would be helpful so they did not dropout. It is likewise not surprising that child and parent blinding was effective since this study did not focus on EEG self-regulation as a task to be learned but rather on playing videogames under conditions that were highly similar since even for the most conscientious children in the NFB group, it would be very difficult for them to reliably correlate effort to success in improving their theta/beta ratio since the threshold necessary for this feedback was constantly changing while the percent range of time for receiving positive feedback was fixed.

Given the above, it is important to emphasize that despite the authors' claims to the contrary, they **did not** demonstrate that "*a large double-blind RCT is feasible*." Their 'feasibility' study **did not** show that 1) it is possible to provide true NFB in which the clinicians "*manually change the threshold*" to maximize learning yet are blind to the experimental condition; 2) there will be high levels of retention in both experimental groups if the focus is on "*the EEG as a task*" versus the subjects playing their favorite videogames; and 3) that children and parents would remain adequately blinded when competently administered NFB is compared to sham feedback. **None of these critical factors in determining whether or not "*a large double-blind RCT is feasible*" were evaluated in the OSU group's study.**

As mentioned previously, Dr. Lofthouse is the lead author of three review articles published during the past two years, each of which strongly argues that a “*large double-blind RCT*” is “*necessary to test specific NF effectiveness*” due to his claimed inadequacies of the 35+ years of NFB research demonstrating its effectiveness in treating ADHD’s core symptoms . Similar to Loo/Barkley, in each of these reviews Dr. Lofthouse applies evidentiary standards to evaluating NFB that he does not apply to his preferred treatments of behavior therapy (of which NFB is a subtype) and CBT. ***Now we have this new false claim by the OSU research group;*** that their study’s findings demonstrate that such a large double-blind trial is feasible. This combination of biased review articles and new false claim suggests that Dr. Lofthouse and his OSU colleagues are far more interested in securing NIMH funding for their proposed large trial than sound science; particularly since their feasibility study did not demonstrate that such an endeavor is even possible. ***Thankfully to date, NIMH has rejected wasting any more taxpayer funding on the OSU group’s misguided efforts.***

**Fourth**, attempting to make the clinician superfluous via blinding strategies becomes even more problematic when evaluating newer NFB training methodologies. Like all behavior therapies, NFB scientists/practitioners continuously seek to improve their treatment methodologies in ways that are consistent with learning theory and the science of operant conditioning.

An example of such newer methodologies is Professor Ulrike Leins and his German colleagues who in a randomized controlled trial, compared theta/beta NFB to slow cortical potential training (see table 5).<sup>49</sup> The NFB training for both groups consisted of 30 60-minute sessions divided into three 2-week phases of 10-sessions each that were each separated by a break of four to six weeks. For both groups, 23% of each NFB session was spent on ***transfer trials*** in which the subjects attempted to activate the targeted EEG pattern via self-regulation alone without real-time feedback and only learned if they had been successful at the end of each transfer trial. Furthermore, the authors developed ***transfer exercises*** for the children to practice at home during the four to six week breaks between the first two blocks of 10 NFB sessions. The children were taught how to use their self-regulation strategies for EEG activation in everyday life situations especially in problematic ones such as while doing homework or in school where sustained attention and concentration are required. The home training exercises included the use of memory aids. During the third block of 10 NFB sessions, the subjects practiced exercising EEG activation while doing their homework at the end of each NFB session under the supervision of the NFB clinician. This progression from 1) teaching EEG self-regulation using real-time feedback to, 2) confirming the learning of EEG self-regulation in transfer trials without real-time feedback, only EEG monitoring to confirm learning and then providing feedback at the end of the trial to, 3) promote generalization using EEG activation exercises at home during tasks requiring sustained concentration, is consistent with other behavior therapy interventions that seek to maximize the generalization of treatment effects.

The outcomes from this study were particularly impressive as 1) both groups learned how to intentionally regulate cortical activity consistent with their NFB training with positive effects in ADHD’s core symptoms as well as IQ; 2) these positive effects remained stable six months after treatment termination; 3) in the two-year follow-up, all improvements in behavior and attention that had been observed at previous assessments remained stable with further significant reductions in the number of

reported ADHD problems and significant further improvement in attention; 4) EEG-self regulation skills were maintained for the children in both groups when reassessed six months and two years after NFB treatment ended; and 5) in each group, half of the children no longer met the criteria for ADHD.<sup>66</sup>

***While the results from this study are certainly impressive, the point here is how can such a multifaceted behavioral intervention be evaluated using clinicians who are blind to what they are doing? Furthermore, what justification do Loo/Barkley and Lofthouse among others have for holding NFB to a different evidentiary standard than they do to other forms of behavior therapy that happen to be their preferred treatments?***

***Fifth***, if we think for a moment about studies designed to test the efficacy of a pill, it is relatively easy to administer a sham treatment; the treatment group takes the real pill, the sham group takes an inert pill, and neither of the experimental groups nor the treating physicians are informed about which is which. As Harvard Professor Irving Kirsch documents though,<sup>85</sup> in such studies the blind is routinely broken by both the physicians overseeing treatment and the experimental subjects due to the informed consent process in which the subjects (& if underage, the subjects' parents) are given a detailed description of potential side-effects which are then reported to the physicians during the ongoing study visits. High rates of side-effects are common with most psychotropic medications, ***particularly fast-acting stimulant medications with their frequent side-effects of insomnia, loss of appetite, dizziness, headaches, and stomachaches among others.***

Furthermore, as Professor Kirsch points out the often marginal (if any) superiority of the active medication over the inert placebo is reduced further when an active placebo is used; that is, a placebo that produces side-effects and thereby reduces the incidence of breaking the blind. Little wonder then that side-effect producing placebos are virtually never used in the gold standard 'double-blind placebo-controlled' drug trials. This gold standard is a fool's gold, best illustrated by what even NIMH's Director Thomas Insel acknowledges<sup>43</sup> is the failure to significantly improve outcomes from psychotropic medications over the past 40+ years despite billions of research dollars that have been spent using this methodology. As both Harvard Psychiatry Professors Maurizio Fava and Andrew Nierenberg separately observed, it only takes two 'randomized double-blind placebo-controlled' trials showing drug superiority to win FDA approval regardless of how many such studies were conducted.<sup>86,87</sup> Both Professors Fava and Nierenberg's articles cite the example of paroxetine that took nine such 'scientifically rigorous' studies to get the two necessary to 'win' FDA approval;<sup>88</sup> ***and this is the fool's gold standard that Drs. Loo, Barkley, Lofthouse and his OSU colleagues want to foist onto NFB before acknowledging its efficacy.***

***Sixth***, sham feedback is not inert; particularly in studies where the focus is on teaching EEG self-regulation as a task versus playing one's preferred videogame. If you hook control subjects up to an EEG device, provide them with a sham computer bar graph, then tell them that this graph represents their brain activity and instruct them to try and raise the bar for 40 minutes, and repeat this for 30 to 40 sessions, this is not the same as taking an inert pill. Assuming that the control subjects are sufficiently motivated and engaged for those 40 minutes, throughout those 30 to 40 sessions, these subjects' brains will be engaged in a continual struggle to make associations between its own ongoing activity and the false feedback. While this is certainly less effective at promoting consistent practice of a desired pattern of EEG activity, the struggle with the false feedback information is still an active

process that likely exercises those aspects of brain functioning that are associated with attention, concentration, frustration tolerance, and determination. For this reason, most NFB scientists argue that sham EEG feedback is not the most appropriate control condition for testing the efficacy of NFB training.

**Finally**, given the inherent problems of applying to NFB a research methodology that was developed to evaluate the efficacy of medications, before accepting the validity of the findings from a ‘double-blind placebo-controlled’ trial to evaluate NFB, ***the onus is on the advocates of this methodology to first demonstrate in scientifically rigorous studies that:***

- There is an equivalent level of success in subjects learning to self-regulate the targeted EEG pattern when comparing non-blinded to blinded clinicians overseeing the NFB training;
- The sham feedback is in fact shown to be inert on the targeted EEG pattern that is the focus of training in the NFB group; and furthermore
- If the researchers plan to deviate from accepted NFB best practices by using methodologies such as auto-thresholding &/or continuous-play videogame feedback, they need to first demonstrate that these procedures result in equivalent or superior effects on the targeted EEG as do those NFB practices that have been proven effective in over 35 years of research.

Like any applied healthcare science, there are numerous areas warranting additional research efforts to enhance NFB’s efficiency and effectiveness. Given NFB’s 35+ years of demonstrated effectiveness though, it is in these areas that any taxpayer funding should be directed versus pursuing the (self) interests of ADHD researchers who apply an evidentiary standard to NFB that they do not apply to their own preferred treatments. It is long past time for this evidentiary bias to end.

The simple fact is that the behavioral treatments advocated by most ADHD ‘experts’ as being ‘evidence-based’ have at best suspect efficacy. The Hodgson and colleagues’ 2012 meta-analysis of non-pharmacological ADHD treatments, ***which applied the same standard of scientific rigor necessary for study inclusion***, found that behavior modification, school-based behavior therapy, behaviorally-based parent training, and behavioral self-monitoring ***each had negative effect sizes*** compared to the control group conditions prompting the authors to conclude that these commonly-used and healthcare insurance reimbursed ADHD treatments ***“cannot be deemed to be efficacious.”***<sup>67</sup> ***In contrast, NFB was found to be more than twice as effective*** in treating the core symptoms of ADHD than any of the other included treatments. While Hodgson’s meta-analysis did not include Dr. Lofthouse and his OSU colleagues’ ‘evidence-based’ cognitive behavior therapy—*since no such CBT study exists which met their scientific standards for inclusion*—PracticeWise’s evidence-based rankings for the American Academy of Pediatrics ***gave CBT a Level 5, No Support ranking*** for treating ADHD ***compared to a Level 1, Highest Support ranking for NFB***. In the MTA Cooperative study, 14 months of free multi-component behavior therapy, at a conservative cost estimate of over \$10,000 per case (see table 1), failed to result in any significant reduction in core ADHD symptoms compared to those who were simply referred to community care—and during follow-up, those who received this ‘spare-no-expense’ behavior therapy had a ***48% higher rate of psychiatric hospitalization*** than those who had simply been referred to community-based professionals with or without actually receiving care (12.3% versus 8.3%). Furthermore, in this largest ever NIMH-funded effectiveness study, 14 months of combined systematic

medication management with behavior therapy failed to separate from medication alone on any direct comparison of the primary ADHD outcomes. ***The clear evidence from the MTA Cooperative study and the Hodgson meta-analysis is that traditional behavior therapy treatments—even at their very best—are not sufficiently helpful for the majority of children and families struggling with ADHD.***

The contrast between the MTA Cooperative study findings and those from the recently published Duric et al. large randomized controlled trial comparing NFB to stimulant medication and combined NFB/medication are telling. Whereas in the MTA study, 14 months of intensive multi-component behavior therapy combined with medication failed to provide any additional benefit over medication alone in reducing ADHD's core symptoms; in the Duric study (see table 5), stimulant medication combined with NFB failed to provide any additional benefit in reducing ADHD's core symptoms over a mere 30 sessions of NFB as a standalone treatment. Furthermore, although not significant, the standalone NFB group averaged more than twice the improvement in parental ratings of attention compared with the other two treatment groups and NFB's effect size was larger than them both on the inattention and hyperactivity subscales as well as the ADHD total score measure.<sup>62</sup> ***Just as it is past time to end the evidentiary bias against NFB, so is it also long past time to end the healthcare insurance reimbursement bias against NFB as well. NFB clearly ranks high as an evidence-based treatment for ADHD and thereby warrants insurance reimbursement for it now.***

**Table 1**  
**Systematic Medication Management and Behavior Therapy**  
**Components in the MTA Cooperative Study**

<p>Systematic Medication Management</p>	<p>Systematic medication management included:</p> <p>An initial 28-day double-blind, daily switch titration of methylphenidate hydrochloride, using 5 randomly ordered repeats each of placebo, 5mg, 10 mg, and 15 or 20 mg given at breakfast and lunch with a half dose in the afternoon. Experienced clinicians blindly reviewed graphs of daily-administered parent and teacher ratings of the child’s responses to each of the three doses and placebo and by consensus selected his/her best dose. The agreed-on dose (if not placebo) became the child’s initial maintenance dose. This was done to yield optimal symptom reduction and minimal side effects for each child.</p> <p>If the child did not obtain an adequate response to methylphenidate during titration, the pharmacotherapist performed non-blinded trials of 3 or more additional medications and evaluating the effectiveness of each trial based on parent and teacher ratings of the child’s responses to same.</p> <p>Provided monthly half-hour office visits with the pharmacotherapist to review parent concerns, evaluate progress, and provide advice, support, and recommend readings to the parent.</p> <p>The pharmacotherapist communicated monthly by phone with the child’s teachers and readjusted medications if the child was not doing well.</p> <p><b>Cost Estimate:</b> Selection of optimal dose \$800  13 half-hour office visits x \$110 per visit = \$1,430  13 teacher phone calls x \$40 per call = \$520  14 months of medication x \$100 per month = \$1,400.00  <b>Total Cost Estimate:</b> \$800+\$1,430+\$520+\$1,400 = <b>\$4,150.00</b></p>
<p>Parent Training</p>	<p>Parent training involved 27 group and 8 individual sessions per family. It began weekly on randomization, concurrent with biweekly teacher consultation; both were tapered over time. The same therapist-consultant conducted parent training and teacher consultation.</p> <p><b>Cost Estimate:</b> 27 group sessions x \$50 per group = \$1,350  8 individual sessions x \$120 per session = \$960</p>
<p>Child-Focused Treatment</p>	<p>Child-focused treatment involved an 8-week, 5-days-per-week, 9-hours per-day summer camp using intensive behavioral interventions administered by counselors/aides, supervised by the same teacher-consultants who performed parent training and teacher consultation. Behavioral interventions were delivered in group-based recreational settings, and included a point system tied</p>

	<p>to specific rewards, time out, social reinforcement, modeling, group problem-solving, sports skills, and social skills training. The summer treatment program included classrooms that provided individualized academic skills practice and reinforcement of appropriate classroom behavior.</p> <p><b>Cost Estimate:</b> \$300 per week x 8 weeks = \$2,400</p>
School-Based Treatment	<p>School-based treatment had 2 components: 10 to 16 sessions of biweekly teacher consultation focused on classroom behavior management strategies and 12 weeks (60 school days) of a part-time, behaviorally trained, paraprofessional aide working directly with the child. The aides had been counselors in the summer camp, and the program continued in the fall classroom, to generalize gains to classrooms. Throughout the school year, a daily report card linked home and school. The daily report card was a 1-page teacher-completed checklist of the child's successes on specific preselected behaviors, and was brought home daily by the child to be reinforced by the parent with home-based rewards (eg, television time, snacks).</p> <p><b>Cost Estimate:</b> 16 teacher consultation sessions x \$120 per session = \$1,920 60 days of in-school aide x \$80 per day = \$4,800</p> <p><b>Total Cost Estimate for BT:</b> \$1,350+\$960+\$2,400+\$1,920+\$4,800 = <b>\$11,430</b></p>
Combined SMM and BT	<p>Combined treatment provided all treatment components outline above in an integrated manner. Information was regularly shared between the behavioral psychologist/teacher-consultant and pharmacotherapist. Manualized guidelines determined if and when an adjustment in one treatment should be made versus first intervening with the other.</p> <p><b>Cost Estimate:</b> Information sharing and ongoing psychologist/pharmacotherapist consultations \$1,400.00</p> <p><b>Total Cost Estimate:</b> \$1,400+\$4,150+\$11,430 = <b>\$16,980</b></p>
Additional Treatment	<p>The SMM, BT, and combined SMM/BT groups were authorized up to 8 additional sessions to use when needed to address clinical emergencies and/or instances of possible dropout from the study. At the end of the 14 months of study-directed treatment, these children/families were also provided with recommendations for ongoing treatment as warranted combined with referrals to medical and behavioral health professionals practicing in their community.</p>
Referral to Community Care	<p>Parents of children assigned to community care were provided a report of the initial study assessments along with a list of community mental health resources. Two-thirds of the community care children received ADHD medications from their own provider during part or all of the 14 months.</p>

**Table 2**  
**Animal Studies of Neurofeedback**

Study	Design	Key Findings
Fetz EE and Finocchio DV <i>Science</i> 1971	Subject was <b>1 adult rhesus macaque monkey</b> ; electrical activity of single neurons was monitored by single electrodes implanted in the motor cortex; electrical activity of arm muscles was monitored using EMG; Muscle and neuron activity was reported to the monkey with an auditory cue and visible meter and a juice reward was given when a certain threshold of muscle or neuron activity was attained. The monkey successfully learned to contract individual muscles while suppressing other muscles and muscle contraction was associated with electrical activity in recorded neurons. The monkey was then successfully trained to produce electrical activity in these neurons in the absence of any muscle contraction.	<p><b>1)</b> Neurons in motor cortex fire bursts of action potentials in association with contraction of one particular muscle.</p> <p><b>2) Through operant conditioning, a monkey can learn to alter the firing pattern of motor cortex neurons in the absence of muscle contraction.</b></p> <p><b>3)</b> This demonstrates that the relationship between neuronal activity and behavior is flexible, or plastic, and can be altered with training even in the adult monkey brain.</p>
Ganguly K et al. <i>Nature Neuroscience</i> 2011	Subjects were <b>2 adult rhesus monkeys</b> ; electrical activity of large ensembles (groups) of neurons was monitored by arrays of electrodes implanted in the motor cortex. Monkeys first learn to use a joystick to guide a cursor to a target on a computer screen (Manual control). Firing rate and preferred movement direction of up to 60 neurons is monitored. The monkey is then required to hold his arm completely still, and activity of 15 randomly selected neurons is translated into cursor movement by a computer (Brain control). Successful target hits result in a juice reward. Within 11 days monkeys learned to move the cursor in Brain control just as effectively as during Manual control. During Brain control, neurons exhibited increased firing in response to a new preferred direction. These newly learned patterns of neuronal activity were stable over many days and Monkeys could switch rapidly back and forth between Manual control and Brain control.	<p><b>1)</b> When learning to use a brain machine interface through neurofeedback training, wide spread changes take place in the network of neurons in motor cortex.</p> <p><b>2)</b> These changes do not interfere with neural activity during Manual control. As monkeys switch rapidly back and forth between Manual and Brain control, individual neurons rapidly shift their mode of activity, indicating that the newly established circuit for Brain control can coexist with the previously established circuit for Manual control.</p> <p><b>3) These changes in neuronal activity emerged during learning and, once established, were stable over long periods.</b></p>
Schafer RJ and Moore T <i>Science</i> 2011	Subjects were <b>2 adult rhesus monkeys</b> ; activity of large ensembles of neurons was monitored by arrays of electrodes implanted in the frontal eye field region of cortex, a brain region important for controlling visual attention. The firing rate of recorded neurons was reported to the	<p><b>1)</b> Using neurofeedback training, monkeys learned to increase or decrease the firing rate of neurons in a region of frontal cortex that is important for visual attention.</p>



	<p>monkey using an auditory cue and when a targeted increase (UP trial) or decrease (DOWN trial) in firing rate was achieved, monkeys were given a juice reward. Over several days, monkeys learned to volitionally increase or decrease neuron firing rate. A visual perception task was then interleaved among the UP and DOWN trials. In this task, monkeys must make an eye movement toward a target shape that appeared along with other shapes on a screen in front of the monkey. If the visual perception task occurred immediately following an UP trial, the number of misses (visual target is present but the monkey fails to make the eye movement) was significantly lowered.</p>	<p><b>2)</b> Performance on a task that requires visual attention was enhanced following volitional increases in neuron firing.  <b>3) These results suggest that the ability to control the activity of populations of neurons, gained through neurofeedback training, can improve cognitive performance on a task relevant to the brain region being trained.</b>  <b>4) Because monkeys cannot be told the goal of the neurofeedback training, this enhancement in cognitive performance cannot be due to placebo effects.</b></p>
<p>Philippens IHCHM and Vanwersch RAP <i>Learning and Memory</i> 2010</p>	<p>Subjects were <b>4 adult male marmoset monkeys</b>; neural activity was monitored through 2 EEG electrodes embedded in skull above sensorimotor cortex and a light signaled to monkeys that a trial had begun. When EEG analysis detected an increase in alpha frequency (8-15Hz, sensorimotor rhythm) brain activity, a computer controlled carousel on top of the cage dispensed a marshmallow treat. Although there were differences in speed of learning, by 4-5 sessions all monkeys had learned to increase alpha frequency activity to receive rewards. Qualitative observation indicates that monkeys experienced motor relaxation during increases in alpha frequency. If rewards were withheld, monkeys behaved as though they were expecting treats.</p>	<p><b>1) Using an EEG neurofeedback apparatus similar to that employed in human studies, monkeys successfully learned to increase alpha frequency brain activity.</b>  <b>2)</b> Qualitative observation suggests that monkeys experienced motor relaxation during alpha frequency brain activity and that monkeys could "feel" subjectively when they had attained the desired brain state.</p>

Abbreviations:

EMG = Electromyograph

EEG = Electroencephalography

**Table 3**  
**Studies of EEG Neurofeedback Targeting Cognitive Functioning in Healthy Adult Subjects**

Study	Design	Key Findings
<p>Egner T and Gruzelier JH. <i>Neuroreport</i> 2001; Egner T and Gruzelier JH. <i>Clin Neurophysiol</i> 2004.</p>	<p>Subjects were <b>45 college or music conservatory students</b>. Subjects underwent NFB training to increase beta, increase SMR, or both types of training; training sessions were 1-2 times per week for 5-10 weeks. <b>Outcome measures</b> included pre/post training administration of TOVA to examine attention and EEG examination of P300 amplitude during auditory oddball task to examine electrophysiological changes in brain function. A <b>control group</b> took only the pre/post tests and did not undergo NFB training.</p>	<p><b>1)</b> NFB training led to improved performance on the TOVA with the most consistent effect being an increase in perceptual sensitivity (ratio between correct responses/incorrect responses).  <b>2)</b> Improved performance on the TOVA is correlated with how successfully subjects learned to modulate brain activity during NFB.  <b>3)</b> NFB training led to increased P300 amplitudes during the oddball task, indicating that training led to changes in electrophysiological properties of brain circuits that are relevant for sensory perception and attention.  <b>4)</b> These effects on performance cannot be due to practice on the pre/post tests because similar improvements were not observed in the control group.  <b>5)</b> Effects on performance and brain electrophysiology cannot be due to some generalized effect of being hooked up to the NFB apparatus and doing NFB training because distinct training protocols showed distinct effects on performance.</p>
<p>Vernon D et al. <i>Int J Psychophysiol</i> 2003 Vernon D et al. <i>Int J Psychophysiol</i> 2003</p>	<p>Subjects were <b>30 medical school students</b>. Subjects underwent NFB training to increase theta or increase SMR; 2 training sessions per week for 4 weeks. <b>Outcome measures</b> included pre/post training administration of a go/no-go test of attention and a word recall test of working memory. A <b>control group</b> took only the pre/post tests and did not undergo NFB training.</p>	<p><b>1)</b> Subjects successfully learned to modulate SMR across the training sessions.  <b>2)</b> SMR NFB training led to an improved performance on the go/no-go task.  <b>3)</b> SMR NFB training led to increased recall in the word recall working memory task.  <b>4)</b> Length of training or training conditions (eyes open) may have precluded successful learning of theta NFB.</p>
<p>Hanslmayr S et al. <i>App Psychophysiol and Biofeedback</i> 2005.</p>	<p>Subjects were <b>18 young adults</b>. Subjects underwent NFB training to increase individual upper alpha (IUA) or decrease individual theta using an adaptive threshold; each subject</p>	<p><b>1)</b> After only a single session of training, 50% of subjects successfully learned to modulate IUA and 55% of subjects successfully learned to modulate theta.  <b>2)</b> Alpha RESPONDERS showed enhanced performance on the</p>

	<p>underwent one session of each type of training on a single day. <b>Outcome measures</b> were an EEG analysis with 30 electrode cap to evaluate changes in brain activity and a mental rotation test of intelligence that was administered before training, after one type of training, and again after the second type of training. The order of the type of training was counter-balanced among the subjects.</p>	<p>mental rotation task after alpha NFB training and degree of success in alpha modulation correlated with improvement on performance of the mental rotation task; NON-RESPONDERS did not exhibit improvements on the mental rotation task.</p> <p><b>3)</b> EEG analysis showed that following NFB training, Alpha RESPONDERS exhibited increased levels of alpha immediately before stimulus presentation during the mental rotation task; high resting alpha before task performance has been correlated with better cognitive performance.</p> <p><b>4)</b> These elevations in pre-stimulus alpha were seen throughout parietal and occipital cortex indicating that NFB training at one site can impact brain function across broader regions.</p>
Rasey HW et al. <i>J Neurotherapy</i> 1996	<p>Subjects were <b>4 college students</b> who underwent NFB training to increase beta activity; Subjects had 2.0-2.5 GPA and no diagnosis of learning disorder or previous experience with NFB. 20 sessions of training were carried out. <b>Outcome measures</b> included pre/post training tests of attention (IVA), intelligence (WAIS-R), and an EEG assessment of power spectrum</p>	<p><b>1)</b> 2 of the subjects successfully learned to modulate beta activity during the course of the training.</p> <p><b>2)</b> These RESPONDERS exhibited an increase in full attention quotient on the IVA, as well as an increase in auditory attention quotient and visual attention quotient; similar improvements were not observed in the NON-RESPONDERS.</p> <p><b>3)</b> No distinct pattern of pre/post changes in the WAIS-R intelligence scale or the no distinct pattern of changes in the EEG assessment of baseline spectra characteristics were noted but the small number of subjects in this study precludes definitive statements.</p>
Zoefel B et al. <i>NeuroImage</i> 2011	<p>Subjects were <b>14 college students</b>. Subjects underwent NFB training to increase individual upper alpha; 1 training session per day for 5 days. <b>Outcome measures</b> consisted of a mental rotation task that tests intelligence administered pre/post NFB training. A <b>control group</b> of 10 college students took the mental rotation test twice, one week apart but did not undergo NFB training</p>	<p><b>1)</b> The majority of subjects (n=11) learned to successfully modulate individual upper alpha during the course of the NFB training.</p> <p><b>2)</b> In these alpha RESPONDERS, increases in alpha amplitude were not only seen during the course of individual training sessions, but baseline alpha activity was progressively higher with each day of training, indicating that effects of training can be additive and carry over from one session to the next; the control group did not show any changes in baseline activity on day 1 compared to day 5.</p> <p><b>3)</b> Alpha RESPONDERS showed significantly larger improvement on the mental rotation task than the control group; they were not instructed to actively modulate alpha during the mental</p>

		<p>rotation task, so these are changes in baseline function induced by NFB training.</p> <p><b>4)</b> EEG analysis indicates that the changes in brain activity induced by NFB training are Hz specific and relatively brain region specific.</p>
<p>Mohr B et al. <i>Neurosci Lett</i> 1998; Pulvermuller F et al. <i>Biol Psychol</i> 2000</p>	<p>Subjects were <b>12 adults</b>. Subjects underwent NFB training to learn to increase and decrease slow cortical potentials (SCPs) in the region of the cortex associated with language processing (perisylvian cortices); 12-24 training sessions were carried out over a period of 3-4 weeks. <b>Outcome measures</b> 1) a lexical processing task in which subjects must distinguish between visually presented words and pseudo words while modulating SCPs up or down. 2) A control test of reaction time to flashing lights to measure visual perception and sensory processing / motor execution</p>	<p><b>1)</b> By the 10-12th training session, 50% of subjects had successfully learned to increase or decrease SCPs in response to a cue.</p> <p><b>2)</b> In RESPONDERS, this modulation of SCPs was seen to be relatively region specific.</p> <p><b>3)</b> RESPONDERS exhibited significantly reduced reaction time on the lexical task during down trials compared to up trials; for NON-RESPONDERS, there was no difference in RT between up and down trials.</p> <p><b>4)</b> There weren't any changes in reaction time to flashes of light when comparing LEARNERS vs. NON-LEARNERS or when comparing up or down trials indicating that there wasn't a change in general sensory perception or cognitive processing but instead that NFB had induced a domain specific change in brain function.</p>
<p>Keizer AW et al. <i>NeuroImage</i> 2010; Keizer AW et al. <i>Int J Psychophysiol</i> 2010</p>	<p>Subjects were <b>31 young adults</b> who were randomly assigned to different NFB groups; both subjects and experimenters were blind as to which NFB protocol was being applied. One group underwent training to increase gamma band activity, a second underwent training to increase beta band activity, and a third group underwent training to increase beta band coherence between a frontal and occipital recording site. 7-8 training sessions of 30min each were carried out over period of 10-11 days using an adaptive threshold for all training protocols. <b>Outcome measures</b> included Pre/Post training tests of visual feature binding, intelligence (RPM), and a test of long term memory</p>	<p><b>1)</b> Subjects were able to learn to modulate gamma band activity and beta band coherence over the course of the training.</p> <p><b>2)</b> Increased gamma band coherence was seen in both the gamma band group and the beta coherence group even though this was not explicitly trained in either group; NFB can impact brain function beyond what is immediately trained.</p> <p><b>3)</b> Gamma band group shows decreased binding costs (enhanced performance, more flexibility) in the visual binding task; fact that this finding is specific to the gamma band group shows that this is a specific behavioral effect of this NFB induced modulation and not some general effect that comes with any form of NFB training.</p> <p><b>4)</b> At the group level there were no significant differences in pre/post intelligence measures; However, the percent change on the intelligence score for an individual correlates with the percent change in gamma power.</p>

		<b>5) Both groups showed improved performance on the long term memory task, slight differences in which aspects of performance were enhanced.</b>
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Abbreviations:

NFB = Neurofeedback  
SCP = Slow Cortical  
Potentials

Tests of Attention:

IVA = Integrated Visual and  
Auditory continuous performance  
task  
TOVA = Test of Variables of  
Attention

Tests of Intelligence:

RPM = Raven's Standard Progressive Matrices  
WAIS-R = Wechsler Adult Intelligence Scale - Revised

**Table 4**  
**Lubar & Shouse's Seminal Study**

Experimental Design	Key Findings
<p>4 ADHD boys who had demonstrated being responsive to Ritalin treatment were selected for the study. The study used a reversal design in which each boy acted as his own experimental control to assess the impact of SMR training on hyperkinetic syndrome. The six treatment phases were 1) No Ritalin; 2) Ritalin-Only; 3) Ritalin and SMR training I (<i>increase</i> 12-14 Hz &amp; <i>decrease</i> 4-7Hz over the sensory motor cortex); 4) Ritalin and SMR reversal/counterconditioning training (<i>decrease</i> 12-14 Hz &amp; <i>increase</i> 4-7Hz); 5) Ritalin and SMR training II; and 6) No Ritalin and only SMR training. The dosage of Ritalin was held constant in phases 2-5. The outcome measures were 13 behavioral indices of over-activity &amp; inattention rated by research assistants in the classroom blind to the experimental conditions and EEG &amp; EMG (muscle tension) recordings in the laboratory.</p>	<ul style="list-style-type: none"> <li>• Relative to No Ritalin, the amount of SMR activity increased in all subjects during the Ritalin-Only phase.</li> <li>• One boy was dropped from the study because he failed to increase his rate of SMR during the first SMR training phase. This boy had the highest baseline levels of SMR production during the No Ritalin phase and the smallest increase in SMR production during the Ritalin-Only phase. Attentional deficits were the dominant problematic classroom behavior for this boy whereas it was over-activity for the other 3 boys.</li> <li>• The other 3 boys significantly increased their rate of SMR production during the Ritalin/SMR training I phase and the strength of this increase was positively correlated with the number of SMR training sessions.</li> <li>• Across study phases, EMG recordings moved in the opposite direction as SMR consistent with animal research that increased SMR is correlated with decreased motor activity.</li> <li>• Combining medication and SMR training increased further the improvements in classroom behaviors that had benefited from Ritalin-Only and produced desirable changes in some behaviors that had not benefited from Ritalin alone (e.g., sustained attention).</li> <li>• Pre-training SMR activity levels under Ritalin-Only returned during the Ritalin/SMR counterconditioning phase in the 3 remaining boys and their classroom behavior deteriorated during this phase to levels similar to that obtained during the Ritalin-Only phase.</li> <li>• Reinstating SMR training in phase 5 resulted in rapid recovery of training effects in both the laboratory and classroom outcome measures for each of the 3 boys.</li> <li>• The improvements in both the laboratory and classroom outcome measures were sustained for all 3 boys after medication was withdrawn in phase 6.</li> </ul>

**Table 5:  
Controlled Neurofeedback Studies in Treating ADHD**

Study	Subjects/Design	Key Findings
Carmony et al. 2001 <sup>63</sup>	<b>16 children</b> ages 8-10, 8 with and 8 without ADHD. Children were randomly assigned to 2 groups of 4 matched pairs. The 1st group (4 with & 4 without ADHD) received 36 - 48 NFB training sessions at school. The 2nd group served as a wait-list control group. All children were unmedicated. <b>Outcome measures</b> included teacher-completed ADDES and the TOVA. All measures were administered before NFB training, at the midpoint, and after training.	<ol style="list-style-type: none"> <li><b>1)</b> Only the children with ADHD that were trained with NFB had significantly reduced hyperactivity/ impulsivity as assessed by the TOVA.</li> <li><b>2)</b> Significant TOVA improvements occurred on the Commission Errors (<math>p &lt; .01</math>) and Anticipatory Scores (<math>p &lt; .03</math>) Scales.</li> <li><b>3)</b> Due to study design, TOVA results cannot be attributed to maturation, time of year, repeated testing, or the training setting/experience.</li> <li><b>4)</b> Teachers' ratings on the ADDES Inattention scale were significantly (<math>p &lt; .002</math>) improved for the NFB group.</li> </ol>
Monastra, Monastra, & George, 2002 <sup>55</sup>  Long-term follow-up study described in Monastra, 2005 <sup>65</sup>	<b>100 ADHD children and adolescents</b> ages 6-19 who demonstrated cortical EEG slowing from a central site. 51 subjects received an average of 43 NFB sessions, 49 did not. All patients received stimulant medication & academic support at school (IEP/504 plan with school accommodations) and their parents received a 10-week parenting program. The <b>outcome measures</b> were the Home & School versions of the ADDES, the TOVA, parenting style, and QEEG Attention Index. All pretreatment measures were administered when patients were unmedicated. Post treatment measures were administered 1-year later while medicated, after 1-week off medication, and 3 years after the initial evaluation	<ol style="list-style-type: none"> <li><b>1) Only NFB training resulted in significant improvements on behavioral, TOVA, and QEEG Attention Index measures when medications were withdrawn.</b></li> <li><b>2)</b> On the ADDES, parent &amp; teacher ratings revealed significant (<math>p &lt; .001</math>) improvements in hyperactive/impulsive &amp; inattentive behaviors post-training, 1-week after medications were withdrawn.</li> <li><b>3)</b> Post NFB training, all TOVA scales were improved to the unimpaired range when measured 1- week after medication withdrawal.</li> <li><b>4)</b> Post NFB training, the QEEG Attention Index dropped into the normal range when measured 1-week after medication withdrawal.</li> <li><b>5) 3-year follow-up after initial evaluation revealed that the NFB group alone sustained gains on all measures while unmedicated and 80% of the NFB group had reduced their medications by 50% or more.</b></li> <li><b>6) None of the children who did not receive NFB had been able to reduce their dosage of stimulant medication in the follow-up assessment and 85% had increased their dosage.</b></li> </ol>
Fuchs et al., 2003 <sup>56</sup>	<b>34 ADHD children</b> ages 8-12 were assigned based on parental preference to NFB ( $n=22$ ) or stimulant medication ( $n=12$ ). NFB consisted of 30 60-min sessions with sessions administered 3x's per week. The NFB protocol was either theta/beta or	<ol style="list-style-type: none"> <li><b>1) Both groups showed significant improvement in each of the outcome measures with no significant differences between groups.</b></li> <li><b>2) The authors conclude "These findings suggest that neurofeedback was efficient in improving some of the behavioral concomitants of ADHD in children whose parents favored a nonpharmacological treatment"</b></li> </ol>

	SMR training dependent the child's subtype of ADHD. The doses for the medication group were adjusted during study based on need and ranged between 10 and 60 mg/day. The <b>outcome measures</b> were the TOVA, Attention Endurance Test, parent & teacher rated CBRS, and the WISC.	
Heinrich et al. 2004 <sup>57</sup>	<b>22 ADHD children</b> ages 7-13 were assigned to NFB (n=13) and a wait-list control group (n=9). The NFB children received 25 SCP training sessions over the course of 3 weeks. Starting at week 2, the NFB children were instructed to practice their strategies at home. The <b>outcome measures</b> were the parent rated FBB-HKS, CPT, and event-related potential (P300) during CPT.	<ol style="list-style-type: none"> <li>1) SCP training resulted in significant reductions in core ADHD symptoms as rated by parents.</li> <li>2) SCP training resulted in significant improvements in the more objective laboratory measures compared to those children in the wait-list control group.</li> <li>3) The authors concluded that <b><i>"this study provides first evidence for both positive behavioral and specific neurophysiological effects of SCP training in children with ADHD."</i></b></li> </ol>
Rossiter, 2004 <sup>58</sup>	<b>62 ADHD children and adults</b> ages 7-55 were matched to NFB (n=31) or stimulant medication (n=31) based on patient or parent preference. Patients were matched by (in order) age, sum of 4 baseline TOVA scores, IQ, gender, and ADHD subtype. The medication patients were titrated based on TOVA results and maintained on the dose that maximized TOVA scores. The NFB patients received either 40 sessions in office or 60 at home over 3-3.5 months. The NFB theta/beta protocol was on the left hemisphere for those patients reporting inattention, daydreaming, poor sustained attention, and/or lack of motivation whereas those also reporting impulsivity, distractibility, and/or stimulus-seeking received left and right hemisphere training. The <b>outcome measures</b> were the TOVA for both groups and for the NFB group only either a child or adult ADHD rating scale	<ol style="list-style-type: none"> <li>1) Both the NFB and stimulant medication groups had similar significant improvements in attention, impulsivity, and processing speed on the TOVA with no significant differences between groups.</li> <li>2) The NFB group demonstrated statistically and clinically significant improvement on behavioral measures (Behavior Assessment System for Children, ES = 1.16, and Brown Attention Deficit Disorder Scales, ES = 1.59).</li> <li>3) The author concluded that <b><i>"confidence interval and nonequivalence null hypothesis testing confirmed that the neurofeedback program produced patient outcomes equivalent to those obtained with stimulant drugs."</i></b></li> </ol>
deBeus, 2006; <sup>51</sup> deBeuss & Kaiser,	<b>53 ADHD children</b> ages 7-11 were randomly assigned in a cross-over design to first receive	1) NFB was superior to sham feedback on the IVA's response control and attention scales, on the CPRS's inattentive scale, and the CTRS's inattentive &



2011 <sup>52</sup>	either 20 30-minute theta/beta NFB sessions or 20 sham NFB sessions. After these sessions, the children who had received active NFB received 20 sham sessions & those who had received sham NFB received 20 sessions of theta/beta NFB. Children were assessed after each block of 20 sessions. <b>Outcome measures</b> included the IVA, parent-rated CPRS, and teacher-rated CTRS.	hyperactive-impulsive scales. <b>2) Of the 42 children who completed all 40 sessions, 31 were classified as NFB-learners because their theta/beta EEG ratio improved in the desired direction by one-half a standard deviation or more following active NFB and 11 were classified as NFB non-learners.</b> <b>3) NFB-learners were superior to non-learners on the IVA's response control and attention scales and the CTRS's inattentive, hyperactive-impulsive, and ADHD total score scales.</b>
Levesque et al, 2006 <sup>59</sup>	<b>20 ADHD children</b> ages 8-12 were randomly assigned on a 3:1 ratio basis. The 15 NFB children received 40 sessions of theta/beta training while 5 children were waitlisted. <b>Outcome measures</b> included pre/post changes in fMRI, Digit Span subtest of the WISC, IVA, CPRS Inattention and hyperactivity scales, Counting Stroop and Go/No-Go Tasks.	<b>1) On the fMRI, NFB resulted in significant activation of the right anterior cingulate cortex (ACC), right ventrolateral prefrontal cortex, right dorsal ACC, left caudate nucleus, and left substantia nigra whereas no significant changes were seen in the control group.</b> <b>2) NFB was superior on each of the other outcome measures.</b> <b>3) The authors concluded that NFB "has the capacity to functionally normalize the brain systems mediating selective attention and response inhibition."</b>
Strehl et al, 2006 <sup>53</sup>	<b>25 ADHD children</b> ages 8-13 received 30 SCP NFB sessions lasting 60 minutes in 3 phases of 10 sessions each. Transfer trials without SCP feedback were intermixed with feedback trials to foster generalization of treatment effects. In addition to the NFB sessions, in the third phase children practiced their SCP self-regulation strategy during homework. <b>Outcome measures</b> included parent and teacher ratings of ADHD symptoms (DSM questionnaire for ADHD; Eyberg Child Behavior Inventory; CPRS, and CTRS), IQ (WISC), and a computerized measure of attention.	<b>1) Children with ADHD can learn to regulate slow negative cortical potentials.</b> <b>2) Children's ability to successfully produce SCP shifts in trials without feedback had better clinical outcomes than those children who were less successful.</b> <b>3) Parents and teachers reported significant behavioral and cognitive improvements for the children following SCP training.</b> <b>4) After SCP training, significant improvements in attention and performance IQ score were also observed.</b> <b>5) The positive changes in parent and teachers ratings, attention, and IQ continued when reassessed 6 months after SCP treatment ended.</b>  <b>While this is was not a controlled study, it was included because of its report of 6-month follow-up results and correlating the children's improvement in learning to regulate SCP and to having better clinical outcomes.</b>
Drechsler et al, 2007 <sup>54</sup>	<b>30 ADHD children</b> age 7-13 were partially randomized to NFB (n=17) and a group for cognitive behavioral training CBT (n=13). The randomization allowed therapeutic/practical aspects to be accounted for (e.g., limited age range for children in each group, gender-mixed groups had to have at least 2 of each gender,	<b>1) NFB was superior to CBT in the parent and teacher ratings, particularly in the attention and cognition-related domains.</b> <b>2) Children in both groups showed similar improvement on the neuropsychological measures, however only about half of the NFB group learned to regulate cortical activation during the transfer condition without direct feedback. Behavioral improvements of this subgroup were moderately related to NFB training performance, whereas effective parental support</b>

	<p>children/parents of the NFB group had to be available during vacation for intense training, and some children/parents expressed strong preference for one type of training or wanted to participate in both groups—in these latter cases only the data from the 1<sup>st</sup> treatment was included for analysis). The CBT groups had 15 90-min sessions, once or twice per week and included social skills training, self-management, metacognitive skill training, and training to enhance self-awareness. Parents were invited to participate in the last 15-minutes of each session. The NFB group had 30 45-minute SCP training sessions twice per day for 2 weeks, followed by a 5-week break, then 5 double sessions, once or twice per week for 3 weeks. Parents and children were taught how to practice generalizing SCP activation/deactivation to real life situations. <b>Outcome measures</b> included parent and teacher rated ADHD symptoms (FBB-HKS, CPRS, CTRS, BRIEF), neuropsychological measures for alertness, inhibitory control, selective attention, sustained attention, and switching attention using the TAP and subtest scores from TEA-ch). Learning cortical self-regulation was evaluated by computing the difference between activation during sessions 2 and 3 vs 13 and 14. Parent involvement was assessed via self-report and involvement in CBT and NFB training opportunities.</p>	<p>accounted better for some advantages of NFB training compared to CBT group therapy according to parents' and teachers' ratings  <b>3)</b> The authors concluded that <i>“there is a specific training effect of neurofeedback of slow cortical potentials due to enhanced cortical control. However, non-specific factors, such as parental support, may also contribute to the positive behavioral effects induced by the neurofeedback training.”</i></p>
<p>Leins et al, 2007<sup>49</sup>  Gani et al, 2008 for 2-year follow-up<sup>66</sup></p>	<p><b>38 ADHD children</b> age 7-13 were matched by age, sex, IQ, dx, and medication status <b>and then randomly assigned</b> either theta/beta NFB (n=19) or SCP NFB (n=19). NFB training for both groups consisted of 30 60-minute sessions divided into 3 2-week phases of 10-session each separated by a</p>	<p><b>1)</b> Both NFB groups learned how to intentionally regulate cortical activity consistent with their training and significantly improved in attention and IQ.  <b>2)</b> Parents and teachers reported significant behavioral and cognitive improvements for the children in both NFB groups.  <b>3)</b> The NFB groups did not differ in behavioral or cognitive outcomes.  <b>4) The clinical effects for both NFB groups remained stable six months after</b></p>

	<p>4 to 6 week break for home practice. For both groups, 23% of the NFB sessions were spent on transfer trials in which the subjects attempted to activate the targeted EEG via self-regulation only without real-time feedback and only learned if they were successful after the end of the transfer trial. Both groups also were taught <b>transfer exercises</b> to practice at home during the four to six week breaks between the first two blocks of 10 NFB sessions. The children were taught how to use their self-regulation strategies for EEG activation in everyday life situations especially in problematic ones such as doing homework or in school where sustained attention and concentration are required. The home training exercises included the use of memory aids. During the third block of 10 sessions, the subjects practiced exercising activation while doing their homework at the end of each NFB session under the supervision of the NFB trainer. Three booster sessions were also administered as part of the 6-month and 2-year follow-up assessments and used to calculate EEG self-regulation skills.</p> <p><b>Outcome measures</b> included parent and teacher ratings of ADHD symptoms (DSM questionnaire for ADHD; Eyberg Child Behavior Inventory; CPRS, and CTRS), IQ (WISC), and for the SCP NFB group, SCP amplitude during activation and deactivation tasks; and for the theta/beta group the theta/beta ratio during activation and deactivation tasks.</p>	<p><b>treatment termination.</b></p> <p>5) In the 2-year follow-up, all improvements in behavior and attention that had been observed at previous assessments remained stable <b>with further significant reductions in the number of reported problems and significant improvement in attention.</b></p> <p>6) EEG-self regulation skills were maintained for the children in both groups when reassessed 2 years after NFB treatment ended.</p> <p>7) In each NFB group, <b>half of the children no longer met the criteria for ADHD</b> and only 22% were taking medication for ADHD.</p> <p>8) The authors concluded that, "<b>neurofeedback appears to be an alternative or complement to traditional treatments. The stability of changes might be explained by normalizing of brain functions that are responsible for inhibitory control, impulsivity and hyperactivity.</b>"</p>
Holtmann et al, 2009 <sup>60</sup>	<p><b>34 ADHD children</b>, age 7 to 12, were randomly assigned on a 3:2 ratio basis to receive either 20 theta/beta NFB sessions (N=20) or 20 sessions of Captain's Log (N=14), a cognitive training software program. All children also received a 2-week intensive behavioral day clinic, weekly parent</p>	<p>1) <b>Only NFB resulted in normalization of a key neurophysiologic correlates of response inhibition.</b></p> <p>2) Only NFB resulted in a significant reduction in impulsivity errors on the Stop-Signal test.</p> <p>3) There were no differential effects on parent ratings.</p> <p>4) The combination of both groups receiving intensive all-day behavior therapy</p>

	training, and 79% were on medication for their ADHD. <b>Outcome measures</b> included pre/post change on Stop-Signal test, a neurophysiologic measure of response inhibition (Go/NoGo-N2), and the parent-rated SNAP-IV.	and 79% of the children being on medication may have attenuated the ability to show differences between treatment groups on the parent ratings.
Gevensleben et al., 2009a <sup>48</sup> ; 2009b <sup>50</sup> ; Wangler et al, 2011 <sup>72</sup> ;  Gevensleben et al., 2010 for 6-month follow-up <sup>64</sup>	<b>102 ADHD children</b> , age 8 to 12, were randomly assigned on a 3:2 ratio basis to receive either 36 sessions of NFB or 36 sessions of Skillies, an award-winning German cognitive training software program. The 62 NFB children were further randomized to receive first either a block of 18 theta/beta training sessions OR 18 slow cortical potential (SCP) training sessions and to switch protocols for the second block of 18 NFB sessions. <b>Outcome measures</b> were German rating scales (FBB-HKS and FBB-SSV) blindly administered to teachers and parents at baseline, after 18, and 36 sessions. Pre/Post changes in EEG were assessed along with 6-month follow-up data for the two-thirds of children who had not dropped out or started some other treatment.	<p><b>1)</b> Only NFB produced significant changes in EEG and these changes were specific to each form of NFB training and furthermore, were associated with improvements on the ADHD rating scales.</p> <p><b>2)</b> On the parent and teacher rating scales, improvements in the NFB group were superior to the Skillies group for reducing:</p> <ul style="list-style-type: none"> <li>• Overall ADHD symptoms (<math>p &lt; .005</math> &amp; <math>p &lt; .01</math>, both respectively)</li> <li>• Inattention (<math>p &lt; .005</math> &amp; <math>p &lt; .05</math>, both respectively)</li> <li>• Hyperactivity/Impulsivity (<math>p &lt; .05</math> &amp; <math>p &lt; .1</math>, both respectively)</li> <li>• Oppositional Behavior (<math>p &lt; .05</math>, parent rating only) Delinquent &amp; Physical Aggression (<math>p &lt; .05</math>, parent rating only).</li> </ul> <p><b>3)</b> No significant differences in effects were found between the two NFB protocols (theta/beta training &amp; SCP training).</p> <p><b>4) Overall, at the 6-month follow-up the NFB group continued their improvements compared to the Skillies group.</b></p> <p><b>5) Finally, as only 50% of the NFB group was classified as treatment responders, the authors concluded that “<i>though treatment effects appear to be limited, the results confirm the notion that NFB is a clinically efficacious module in the treatment of children with ADHD.</i>”</b></p>
Bakhshayesh et al, 2011 <sup>61</sup>	<b>35 ADHD children</b> , age 6 to 14, were randomly assigned to receive either 30 theta/beta NFB sessions (N=18) or 30 sessions of electromyography (EMG) biofeedback (N=17). Single-blinded RCT. <b>Outcome measures</b> included pre/post change on parent and teacher ratings using the FBB-HKS; CPT; The bp and d2 attention tests; and changes in the theta/beta ratio and EMG amplitude.	<p><b>1)</b> Training effectively reduced theta/beta ratios and EMG levels in the NF and BF groups, respectively.</p> <p><b>2) Compared to EMG biofeedback, NFB significantly reduced inattention symptoms on the parent rating scale and reaction time and concentration on the neuropsychological measures.</b></p> <p><b>3)</b> While children in both groups made significant improvements on most measures thereby making it difficult with such a small N for NFB to separate from EMG biofeedback, in ALL 11 outcome measures (and subscales thereof), the level of improvement was greater for NFB and a non-parametric binomial test would find this highly significant.</p> <p><b>4)</b> Besides lowering muscular tension, EMG biofeedback teaches attention, which may further reduce the difference in outcomes.</p>

<p>Duric et al, 2012<sup>62</sup></p>	<p><b>130 ADHD children and adolescents</b>, ages 6 to 18, were randomly assigned to receive either 1) NFB, 2) methylphenidate, or 2) combined NFB/medication. After randomization 39 dropped out (36 immediately after randomization) 13 from the NFB group, 15 from the medication group, 11 from the combined group resulting in 91 completing the study; NFB (n=30), methylphenidate (n=31), and combined (n=30). The NFB group received 30 40-minute theta/beta sessions 3 times per week for 10 weeks. The subjects in the medication and combined group took methylphenidate) twice per day at the recommended dose of 1 mg per kg with the final medication doses from 20 to 60 mg daily. <b>Outcome measures</b> were the inattention and hyperactivity subscales of the parent-rated CMADBD-P (&amp; total score) with the post ADBD-P administered one week after the final NFB session for those in the NFB and combined groups.</p>	<p><b>1)</b> The parents reported highly significant effects of the treatments in reducing the core symptoms of ADHD, but no significant differences between the treatment groups were observed.</p> <p><b>2)</b> Although not significant, the NFB group showed more than double the pre-post change in attention compared with the other two treatments (3.1 vs. 1.1 and 1.5 for the means) and NFB’s effect size was larger than the other two treatments on both the inattention and hyperactivity subscales and total score measures.</p> <p><b>3)</b> The authors conclude that, <b><i>“NFB produced a significant improvement in the core symptoms of ADHD, which was equivalent to the effects produced by methylphenidate, based on parental reports. This supports the use of NFB as an alternative therapy for children and adolescents with ADHD.”</i></b></p>
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### Abbreviations

<b>Behavior Rating Scales</b>	<b>Tests of Attention</b>	<b>Tests of Intelligence</b>
<p>ADDES=Attention Deficit Disorder Evaluation Scale            BRIEF=Behavior Rating Inventory for Executive Function            CBRS=Conners Behavior Rating Scale            CMADBD-P=Clinician’s Manual for the Assessment of Disruptive Behavior Disorders – Rating Scale for Parents            CPRS= Conners Parent Rating Scale            CTRS=Conners Teacher Rating Scale            FBB-HKS=German Rating Scale for ADHD            FBB-SSV=German Rating Scale for Oppositional Defiant/Conduct Disorders</p>	<p>CPT=Continuous Performance Test            IVA=Integrated Visual and Auditory continuous performance task            TOVA=Test of Variables of Attention            TAP=Test for Attentional Performance; TEA-ch</p>	<p>WISC=Wechsler Intelligence Scale for Children</p>

## References:

\*\*\* This section, along with tables 2 & 3 and points 5 & 6 in the Appendix were adapted with permission from the paper, “**Neuromodulation Training Technologies: Bringing Neuroscience to the Classroom to Enhance Learning Capacity in Children**” by Lindsay De Biase and Ed Pigott and is available for download at

[http://www.nchouston.org/content/files/Neuromodulation White Paper.pdf](http://www.nchouston.org/content/files/Neuromodulation%20White%20Paper.pdf).

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