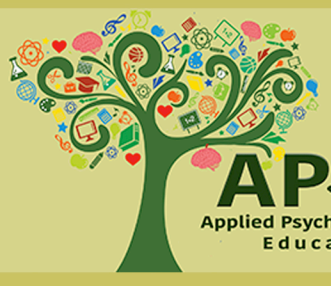
Neurofeedback Bibliography

- ADHD and Related Learning Disabilities
- Anxiety, PTSD and Panic Disorders
- Autism Spectrum Disorders
- Cognitive, Sport and Peak Performance
- Depression and Bipolar Disorder
- Epilepsy and Seizure Disorders
- Sleep Disorders
- Substance Abuse and Addiction Disorders
- Others
- QEEG



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Neurofeedback Bibliography

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Cynthia Kerson, PhD, QEEGD, BCN, BCB

For Mind Builders

Table of Contents

ATTENTION DEFICIT HYPERACTIVITY DISORDER (ADHD) AND RELATED LEARNING DISABILITIES

Alfonso MR., Miquel TF., Xavier B. & Blanca AS. (2013). Resting Parietal Electroencephalogram Asymmetries and Self-Reported Attentional Control. ***Clin EEG Neurosci*****. Mar 31.** Research on electroencephalogram (EEG) asymmetries and anxiety proneness has recently spread to emotion regulation capabilities. We studied whether attentional control (AC), a temperamental construct related to emotional regulation, was associated with asymmetrical patterns of resting EEG activity at the frontal and parietal regions, reflected not only in the α frequency band (8-13 Hz) but also in higher bands $\beta 1$ (13-20 Hz) and $\beta 2$ (20-30 Hz). Self-reports of AC and trait anxiety, and resting EEG recordings, were obtained from 58 healthy participants. Correlational analysis showed that lower levels of self-reported AC were associated with less α, $\beta 1$, and $\beta 2$ powers in the left parietal cortex, while no significant relationships were found between the AC and EEG oscillations in the prefrontal cortex. The role of the left and right parietal lobes in the attentional processes is discussed.

Arns, M., van der Heijden, KB., Arnold, LE. & Kenemans, LJ. (2013). Geographic Variation in the Prevalence of Attention-Deficit/Hyperactivity Disorder: The Sunny Perspective. Biological Psychology. Background: Attention-deficit/hyperactivity disorder (ADHD) is the most common psychiatric disorder of childhood, with average worldwide prevalence of 5.3%, varying by region. Methods: We assessed the relationship between the prevalence of ADHD and solar intensity (SI) (kilowatt hours/square meters/day) on the basis of multinational and cross-state studies. Prevalence data for the U.S. were based on self-report of professional diagnoses; prevalence data for the other countries were based on diagnostic assessment. The SI data were obtained from national institutes. Results: In three datasets (across 49 U.S. states for 2003 and 2007, and across 9 non-U.S. countries) a relationship between SI and the prevalence of ADHD was found, explaining 34%-57% of the variance in ADHD prevalence, with high SI having an apparent preventative effect. Controlling for low birth weight, infant mortality, average income (socioeconomic status), latitude, and other relevant factors did not change these findings. Furthermore, these findings were specific to ADHD, not found for the prevalence of autism spectrum disorders or major depressive disorder. Conclusions: In this study we found a lower prevalence of ADHD in areas with high SI for both U.S. and non-U.S. data. This association has not been reported before in the literature. The preventative effect of high SI might be related to an improvement of circadian clock disturbances, which have recently been associated with ADHD. These findings likely apply to a substantial subgroup of ADHD patients and have major implications in our understanding of the etiology and possibly prevention of ADHD by medical professionals, schools, parents, and manufacturers of mobile devices.

Arns, M., Conners, CK., Kraemer, HC. (2013). A decade of EEG theta/beta ratio research in ADHD: A meta-analysis. ***Journal of Attention Disorders*****:May** DOI:10.1177/108705471246008. Objective: Many EEG studies have reported that ADHD is characterized by elevated Theta/Beta ratio (TBR). In this study we conducted a meta-analysis on the TBR in ADHD. Method: TBR data during Eyes Open from location Cz were analyzed from =children/adolescents 6-18 years of age with and without ADHD. Results: Nine studies were identified with a total of 1253 children/adolescents with and 517 without ADHD. The grand-mean effect size (ES) for the 6-13 year-olds was 0.75 and for the 6-18 year-olds was 0.62. However the test for heterogeneity remained significant; therefore these ESs are misleading and considered an overestimation. Post-hoc analysis found a decreasing difference in TBR across years, explained by an increasing TBR for the non-ADHD groups. Conclusion: Excessive TBR cannot be considered a reliable diagnostic measure of ADHD, however a substantial sub-group of ADHD patients do deviate on this measure and TBR has prognostic value in this sub-group, warranting its use as a prognostic measure rather than a diagnostic measure.

Arns, M., Kenemans, JL. (in press). Neurofeedback in ADHD and insomnia: Vigilance stabilization through sleep spindles and circadian networks. Ne*urosci. Biobehav. Rev*. (2012). In this review article an overview of the history and current status of neurofeedback for the treatment of ADHD and insomnia is provided. Recent insights suggest a central role of circadian phase delay, resulting in sleep onset insomnia (SOI) in a sub-group of ADHD clients. Chronobiological treatments, such as melatonin and early morning bright light, affect the suprachiasmatic nucleus. This nucleus has been shown to project to the noradrenergic locus coeruleus (LC) thereby explaining the vigilance stabilizing effects of such treatments in ADHD. It is hypothesized that both Sensori-Motor Rhythm (SMR) and Slow-Cortical Potential (SCP) neurofeedback impact on the sleep spindle circuitry resulting in increased sleep spindle density, normalization of SOI and thereby affect the noradrenergic LC, resulting in vigilance stabilization. After SOI is normalized, improvements on ADHD symptoms will occur with a delayed onset of effect. Therefore, clinical trials investigating new treatments in ADHD should include assessments at follow-up as their primary endpoint rather than assessments at outtake. Furthermore, an implication requiring further study is that neurofeedback could be stopped when SOI is normalized, which might result in fewer sessions.

Arns M, Drinkenburg W, Leon Kenemans J. (2012). The effects of QEEG-informed neurofeedback in ADHD: an open-label pilot study. ***Appl Psychophysiol Biofeedback.*** **2012 Sep;37(3):171-80.** ADHD several EEG biomarkers have been described before, with relevance to treatment outcome to stimulant medication. This pilot-study aimed at personalizing neurofeedback treatment to these specific sub-groups to investigate if such an approach leads to improved clinical outcomes. Furthermore, pre- and post-treatment EEG and ERP changes were investigated in a sub-group to study the neurophysiological effects of neurofeedback. Twenty-one patients with ADHD were treated with QEEG-informed neurofeedback and post-treatment effects on inattention (ATT), hyperactivity/impulsivity (HI) and comorbid depressive symptoms were investigated. There was a significant improvement for both ATT, HI and comorbid depressive complaints after QEEG-informed neurofeedback. The effect size for ATT was 1.78 and for HI was 1.22. Furthermore, anterior individual alpha peak frequency (iAPF) demonstrated a strong relation to improvement on

comorbid depressive complaints. Pre- and post-treatment effects for the SMR neurofeedback sub-group exhibited increased N200 and P300 amplitudes and decreased SMR EEG power post-treatment. This pilot study is the first study demonstrating that it is possible to select neurofeedback protocols based on individual EEG biomarkers and suggests this results in improved treatment outcome specifically for ATT, however these results should be replicated in further controlled studies. A slow anterior iAPF at baseline predicts poor treatment response on comorbid depressive complaints in line with studies in depression. The effects of SMR neurofeedback resulted in specific ERP and EEG changes.

Arns, M, Conners, C. K., & Kraemer, H (2012). A decade or EEG Theta/Beta Ratio Research in ADHD: A Meta-Analysis. *Journal of Attention Disorders*; (in press). Objective: Many EEG studies have reported that ADHD is characterized by elevated Theta/Beta ratio (TBR). In this study we conducted a meta-analysis on the TBR in ADHD. Method: TBR data during Eyes Open from location Cz were analyzed from children/adolescents 6-18 years of age with and without ADHD. Results: Nine studies were identified with a total of 1253 children/adolescents with and 517 without ADHD. The grand-mean effect size (ES) for the 6-13 year-olds was 0.75 and for the 6-18 year-olds was 0.62. However the test for heterogeneity remained significant; therefore these ESs are misleading and considered an overestimation. Post-hoc analysis found a decreasing difference in TBR across years, explained by an increasing TBR for the non-ADHD groups. Conclusion: Excessive TBR cannot be considered a reliable diagnostic measure of ADHD, however a substantial sub-group of ADHD patients do deviate on this measure and TBR has prognostic value in this sub-group, warranting its use as a prognostic measure rather than a diagnostic measure.

Arns, M., de Ridder, S., Strehl, U., Breteler, M., Coenen, A. (2009). Efficacy of neurofeedback treatment in ADHD: The effects on attention, impulsivity and hyperactivity: A meta-analysis. *Clinical EEG and Neuroscience*; 40(3). 180-189. In order to study the treatment of the children with attention deficit hyperactivity disorder (ADHD), the integrated visual and auditory continuous performance test (IVA-CPT) was clinically applied to evaluate the effectiveness of electroencephalogram (EEG) biofeedback training. Of all the 60 children with ADHD aged more than 6 years, the effective rate of EEG biofeedback training was 91.6% after 40 sessions of EEG biofeedback training. Before and after treatment by EEG biofeedback training, the overall indexes of IVA were significantly improved among predominately inattentive, hyperactive, and combined subtype of children with ADHD ($P<0.001$). It was suggested that EEG biofeedback training was an effective and vital treatment on children with ADHD.

Arns, M., Kleinnijenhuis, M., Fallahpour, K., & Bretler, R. (2007). Golf performance enhancement and real-life neurofeedback training using personalized event-locked EEG profiles. *Journal of Neurotherapy*, 11(4), 11-18. Background. This study reports on a new method for golf performance enhancement employing personalized real-life neurofeedback during golf putting. Method. Participants (n = 6) received an assessment and three real-life neurofeedback training sessions. In the assessment, a personal event-locked electroencephalographic (EEG) profile at FPz was determined for successful versus unsuccessful putts. Target frequency bands and amplitudes marking optimal prefrontal brain state were derived from the profile by two raters. The training sessions consisted of four series of 80 putts in an ABAB design. The feedback in the second and fourth series was administered in the form of a continuous NoGo tone, whereas in the first and

third series no feedback was provided. This tone was terminated only when the participants EEG met the assessment-defined criteria. In the feedback series, participants were instructed to perform the putt only after the NoGo tone had ceased. Results. From the personalized event-locked EEG profiles, individual training protocols were established. The interrater reliability was 91%. The overall percentage of successful putts was significantly larger in the second and fourth series (feedback) of training compared to the first and third series (no feedback). Furthermore, most participants improved their performance with feedback on their personalized EEG profile, with 25% on average. Conclusions. This study demonstrates that the "zone" or the optimal mental state for golf putting shows clear recognizable personalized patterns. The learning effects suggest that this real-life approach to neurofeedback improves learning speed, probably by tapping into learning associated with contextual conditioning rather than operant conditioning, indicating perspectives for clinical applications.

Barabasz, A., & Barabasz, M. (2000). Treating AD/HD with hypnosis and neurotherapy. *Child Study Journal*, 30(1), 25-42. Eighteen children and one young adult ADHD patients were treated with alert hypnosis as an adjunct to neurotherapy. Posttest means for each subscale (Inattentive, Impulsive, and Hyperactive) of the Attention Deficit Disorders Evaluation Scale-Home Version were significantly lower than pretest scores. No comparison group was used, and outcomes were confined to specific therapist.

Bazanova, O.M., Aftanas, L.I. (2010). Individual EEG alpha activity analysis for enhancement neurofeedback efficiency: Two case studies. ***Journal of Neurotherapy*** **14(3), 244 - 253.** The hypothesis was tested of whether neurofeedback training applied in order to increase or decrease power of individual EEG frequency ranges is more efficient than neurofeedback training of standard EEG frequency ranges. The sessions of decreasing the theta/beta ratio and reinforcing alpha neurofeedback training were carried out on two outpatients with attention deficit disorder (a schoolboy) and functional pain contraction (a professional musician). The neurofeedback utilizing standard EEG frequency ranges (theta 4-8, alpha 8-12, beta 13-18) was inefficient and even resulted in aggravation of symptoms in both cases. The individualized neurofeedback that utilized individual frequency ranges resulted in substantial clinical improvement.

Beauregard, M., & Levesque, J. (2006). Functional magnetic resonance imaging investigation of the effects of neurofeedback training on the neural bases of selective attention and response inhibition in children with attention-deficit/hyperactivity disorder. ***Applied Psychophysiology & Biofeedback*****, 31(1), 3-20**. Two functional magnetic resonance imaging (fMRI) experiments were undertaken to measure the effect of neurofeedback training (NFT), in AD/HD children, on the neural substrates of selective attention and response inhibition. Twenty unmedicated AD/HD children participated to these experiments. Fifteen children were randomly assigned to the Experimental (EXP) group whereas the other five children were randomly assigned to the Control (CON) group. Only subjects in the EXP group underwent NFT. EXP subjects were trained to enhance the amplitude of the SMR (12-15 Hz) and beta 1 activity (15-18 Hz), and decrease the amplitude of theta activity (4-7 Hz). Subjects from both groups were scanned one week before the beginning of NFT (Time 1) and 1 week after the end of NFT (Time 2), while they performed a "Counting Stroop" task (Experiment 1) and a Go/No-Go task (Experiment 2). At Time 1, in both groups, the Counting Stroop task was associated with significant activation in the left superior parietal lobule. For the Go/No-Go task, no significant activity was

detected in the EXP and CON groups. At Time 2, in both groups, the Counting Stroop task was associated with significant activation of the left superior parietal lobule. This time, however, there were significant loci of activation, in the EXP group, in the right ACC, left caudate nucleus, and left substantia nigra. No such activation loci were seen in CON subjects. For the Go/No-Go task, significant loci of activation were noted, in the EXP group, in the right ventrolateral prefrontal cortex, right ACcd, left thalamus, left caudate nucleus, and left substantia nigra. No significant activation of these brain regions was measured in CON subjects. These results suggest that NFT has the capacity to functionally normalize the brain systems mediating selective attention and response inhibition in AD/HD children.

Becerra J, Fernndez T, Harmony T, Caballero MI, Garcia F, Fernandez-Bouzas A, Santiago-Rodriguez E, Prado-Alcalá RA. (2006) "Follow-up study of learning disabled children treated with neurofeedback or placebo." ***Clinical EEG & Neuroscience*****, 37 (3), 98-203.** This report is a 2-year follow-up to a previous study describing positive behavioral changes and a spurt of EEG maturation with theta/alpha neurofeedback (NFB) training in a group of Learning Disabled (LD) children. In a control paired group, treated with placebo, behavioral changes were not observed and the smaller maturational EEG changes observed were easily explained by increased age. Two years later, the EEG maturational lag in Control Group children increased, reaching abnormally high theta Relative Power values; the absence of positive behavioral changes continued and the neurological diagnosis remained LD. In contrast, after 2 years EEG maturation did continue in children who belonged to the Experimental Group with previous neurofeedback training; this was accompanied by positive behavioral changes, which were reflected in remission of LD symptoms.

Boyd, W. D., & Campbell, S. E. (1998). EEG biofeedback in the schools: The use of EEG biofeedback to treat ADHD in a school setting. ***Journal of Neurotherapy*****, 2(4), 65-71.** Six middle school students diagnosed with attention deficit/hyperactivity disorder were selected for sensory motor rhythm (SMR) training with EEG biofeedback. The subjects were evaluated following a 72-hour drug-free period with the WISC-III Digit Span subtest and the Test of Variables of Attention (TOVA). Five of the subjects received 20 sessions of EEG biofeedback and one of the subjects received nine sessions of EEG biofeedback. The subjects were evaluated again following a 72-hour drug-free period. Five of the six subjects improved on their combined Digit Span, TOVA Inattention, and TOVA Impulsivity scores. These results supported previous findings that EEG biofeedback can be effective in the treatment of attention deficit/hyperactivity disorder. More importantly, this study demonstrated that EEG biofeedback could be used in an actual school setting. Recommendations for implementing an EEG biofeedback program in the schools were provided.

Breteler, M. H. M., Arns, M., Peters, S., Giepmans, I., & Verhoeven, L. (2010). Improvements in spelling after QEEG-based neurofeedback in dyslexia: A randomized controlled treatment study. ***Applied Psychophysiology & Biofeedback*****, 35(1), 5-11.** Phonological theories of dyslexia assume a specific deficit in representation, storage and recall of phonemes. Various brain imaging techniques, including qEEG, point to the importance of a range of areas, predominantly the left hemispheric temporal areas. This study attempted to reduce reading and spelling deficits in children who are dyslexic by means of neurofeedback training based on neurophysiological differences between the participants and gender and age matched controls. Nineteen children were randomized into an experimental group receiving qEEG based neurofeedback (n = 10) and a

control group (n = 9). Both groups also received remedial teaching. The experimental group improved considerably in spelling (Cohen's d = 3). No improvement was found in reading. An indepth study of the changes in the qEEG power and coherence protocols evidenced no fronto-central changes, which is in line with the absence of reading improvements. A significant increase of alpha coherence was found, which may be an indication that attentional processes account for the improvement in spelling. Consideration of subtypes of dyslexia may refine the results of future studies.

Budzynski, T. H. (1996). Brain brightening: Can neurofeedback improve cognitive process? *Biofeedback*, 24(2), 14-17. (Abstract to follow)

Cannon, R., Kerson, C., Hampshire, A. & Coleman, G. L. (2013). Assessing the functional integrity of the default network in adult ADHD with fMRI and sLORETA. *Journal of Neurotherapy*; 16(1). Intrinsic functional connectivity within the default network (DMN) of the brain has gained growing interest in attention deficit/hyperactivity disorder (ADHD). The DMN is proposed to support such core functions as theory of mind, self-related activities such as autobiographical self, stimulus independent thought, self-projection, self-reference and introspective processes as well as central features of self-regulation, task compliance and executive functions. The present study recorded brain activity using both EEG and fMRI during rest and task. The rest data were analyzed using sLORETA and a psychophysiological interaction model respectively. Medial prefrontal and left parietal region connectivity showed the greatest difference when comparing ADHD to control in theta, alpha1 and alpha 2.

Cannon, R., Kerson, C., Hampshire, A. (2011). sLORETA and fMRI Detection of Medial Prefrontal Default Network Anomalies in Adult ADHD. Journal of Neurotherapy; 15(4). 358-373. Attention deficit hyperactivity disorder (ADHD) is a developmental psychiatric disorder thought to affect approximately 5 to 10% of school-age children, of whom 30%-65% continue to exhibit symptoms into adulthood. The prevalence of ADHD in adults is also an estimated 4%, second only to depression. Across studies there appear to be significant network dysfunctions involved in ADHD. Typically the foci of interest in ADHD included the insular cortices, frontal lobes, basal ganglia and cerebellum. More recently, attention has been directed to the default network of the brain and its functional integrity in ADHD with focus on the precuneus and parietal lobes and interactions with medial prefrontal cortices. Functional Magnetic Resonance Imaging (fMRI) measures neurovascular coupling as measured by the blood oxygenated level dependent signal (BOLD). Electroencephalogram (EEG) measures brain electrical information. Since fMRI is an indirect measure of neuronal activity and EEG is a direct measure combining the results from these two imaging modalities under the same task conditions may provide a more complete story as to the what (EEG) and where (fMRI) activity exists.

Carmody, DP., Radvanski, D. C., Wadhwani, S., Sabo, JJ., & Vergara, L. (2001). EEG biofeedback training and attention-deficit/hyperactivity disorder in an elementary school setting. *Journal of Neurotherapy*, 4(3), 5-27. Method: An experimental group of eight children ages 8-10 completed 35-47 sessions of EEG biofeedback training over a six-month period. Four participants in the experimental group were diagnosed with Attention-

Deficit/Hyperactivity Disorder (ADHD) and four were not diagnosed with ADHD. Eight children in the waitlist control group were matched to the experimental group on age, grade, teacher, and diagnosis. None of the 16 participants were medicated for ADHD. Results: Attention abilities as measured by the Test of Variables of Attention showed the experimental group of children with ADHD reduced errors of commission and anticipation, indicating a reduction in impulsivity. Teacher reports using the McCarney Scale indicated improvements in attention but no changes in impulsivity and hyperactivity. Discussion: Several confounds require exploration before attribution of changes are assigned to neurofeedback. Whether the effects are due to the neurofeedback protocols, attendance at individual sessions away from the classroom, the attention of the technician, or the excitement of a special program cannot be determined with this study. It will be necessary to have a placebo group in order to separate systematically the variables in the training program.

Cohen Kadosh KC, Linden DE, Lau JY. (2013). Plasticity during childhood and adolescence: Innovative approaches to investigating neurocognitive development. *Dev Sci*.16(4). 574-583. doi: 10.1111/desc.12054. Epub 2013 May 28. Adolescence is a period of profound change, which holds substantial developmental milestones, but also unique challenges to the individual. In this opinion paper, we highlight the potential of combining two recently developed behavioural and neural training techniques (cognitive bias modification and functional magnetic neuroimaging-based neurofeedback) into a research approach that could help make the most of increased levels of plasticity during childhood and adolescence. We discuss how this powerful combination could be used to explore changing brain-behaviour relationships throughout development in the context of emotion processing, a cognitive domain that exhibits continuous development throughout the second decade of life. By targeting both behaviour and brain response, we would also be in an excellent position to define sensible time windows for enhancing plasticity, thereby allowing for targeted intervention approaches that can help improve emotion processing in both typically and atypically developing populations.

Egner, T., & Gruzelier, J. H. (2001). Learned self-regulation of EEG frequency components effects attention and event-related brain potentials in humans. *NeuroReport,* 12, 4155-4159. Learned enhancement of EEG frequency components in the lower beta range by means of biofeedback has been reported to alleviate attention deficit hyperactivity disorder (ADHD) symptoms. In order to elucidate frequency-specific behavioural effects and neurophysiological mediators, this study applied neurofeedback protocols to healthy volunteers, and assessed impact on behavioural and electrocortical attention measures. Operant enhancement of a 12-15Hz component was associated with reduction in commission errors and improved perceptual sensitivity on a continuous performance task (CPT), while the opposite relation was found for 15-18Hz enhancement. Both 12-15Hz and 15-18Hz enhancement were associated with significant increases in P300 event-related brain potential amplitudes in an auditory oddball task. These relations are interpreted as stemming from band-specific effects on perceptual and motor aspects of attention measures.

Egner, T., & Gruzelier, J. H. (2004). EEG biofeedback of low beta band components: Frequency-specific effects on variables of attention and event-related brain potentials. *Clinical Neurophysiology*, 115(1), 131-139. Objective: To test a common assumption underlying the clinical use of electroencephalographic (EEG) biofeedback training (neurofeedback), that the modulation of discreet frequency bands is associated with frequency-specific effects. Specifically, the proposal was assessed that enhancement of the low beta

components sensorimotor rhythm (SMR: 12 - 15 Hz) and beta1 (15 - 18 Hz) affect different aspects of attentional processing. Methods: Subjects (n ¼ 25) were randomly allocated to training with either an SMR or beta1 protocol, or to a non-neurofeedback control group. Subjects were assessed prior and subsequent to the training process on two tests of sustained attention. The neurofeedback participants were also assessed on target P300 event-related potential (ERP) amplitudes in a traditional auditory oddball paradigm. Results: Protocol-specific effects were obtained in that SMR training was associated with increased perceptual sensitivity 'd prime' (d0), and reduced omission errors and reaction time variability. Beta1 training was associated with faster reaction times and increased target P300 amplitudes, whereas no changes were evident in the control group. Conclusions: Neurofeedback training of SMR and beta1 band components led to significant and protocol-specific effects in healthy subjects. The data can be interpreted as indicating a general attention-enhancing effect of SMR training, and an arousal-enhancing effect of beta1 training.

Enriquez-Geppert S, Huster RJ, Scharfenort R, Mokom ZN, Zimmermann J, Herrmann CS. (2013). Modulation of frontal-midline theta by neurofeedback. Biol Psychol. 2013 Mar 15. pii: S0301-0511(13)00070-7. doi: 10.1016/j.biopsycho.2013.02.019. [Epub ahead of print]. Cortical oscillations demonstrate a relationship with cognition. Moreover, they also exhibit associations with task performance and psychiatric mental disorders. This being the case, the modification of oscillations has become one of the key interests of neuroscientific approaches for cognitive enhancement. For such kind of alterations, neurofeedback (NF) of brain activity constitutes a promising tool. Concerning specific higher cognitive functions, frontal-midline theta (fm-theta) has been suggested as an important indicator of relevant brain processes. This paper presents a novel approach for an individualized, eight-session NF training to enhance fm-theta. An individual's dominant fm-theta frequency was determined based on experiments tapping executive functions. Effects of the actual NF training were compared to a pseudo-NF training. Participants of the pseudo-NF training experienced a comparable degree of motivation and commitment as the subjects of the actual NF training, but found the "training" slightly easier. In comparison to the pseudo-NF training, proper NF training significantly enhanced fm-theta amplitude in the actual training sessions, as well as during the whole course of training. However, unspecific changes in the alpha and beta frequency ranges found with both the actual NF and the pseudo-NF training groups emphasize the relevance of active control groups for neurofeedback studies.

Escolano, C., Navarro-Gil, M., Garcia-Campayo, J., Congedo, M. & Minqueez, j. (2014). The effects of individual upper alpha neurofeedback in ADHD: An open-label pilot study. Applied Psychophysiology and Biofeedback: early E-Pub Sept 9 Standardized neurofeedback (NF) protocols have been extensively evaluated in attention-deficit/hyperactivity disorder (ADHD). However, such protocols do not account for the large EEG heterogeneity in ADHD. Thus, individualized approaches have been suggested to improve the clinical outcome. In this direction, an open-label pilot study was designed to evaluate a NF protocol of relative upper alpha power enhancement in fronto-central sites. Upper alpha band was individually determined using the alpha peak frequency as an anchor point. 20 ADHD children underwent 18 training sessions. Clinical and neurophysiological variables were measured pre- and post-training. EEG was recorded pre- and post-training, and pre- and post-training trials within each session, in both eyes closed resting state and eyes open task-

related activity. A power EEG analysis assessed long-term and within-session effects, in the trained parameter and in all the sensors in the (1-30) Hz spectral range. Learning curves over sessions were assessed as well. Parents rated a clinical improvement in children regarding inattention and hyperactivity/impulsivity. Neurophysiological tests showed an improvement in working memory, concentration and impulsivity (decreased number of commission errors in a continuous performance test). Relative and absolute upper alpha power showed long-term enhancement in task-related activity, and a positive learning curve over sessions. The analysis of within-session effects showed a power decrease ("rebound" effect) in task-related activity, with no significant effects during training trials. We conclude that the enhancement of the individual upper alpha power is effective in improving several measures of clinical outcome and cognitive performance in ADHD. This is the first NF study evaluating such a protocol in ADHD. A controlled evaluation seems warranted due to the positive results obtained in the current study.

Fehmi, L. G., & Selzer, F. A. (1980). ***Biofeedback and attention training*****. Chapter in S. Boorstein (Ed.),** ***Transpersonal Psychotherapy*****. Palo Alto: Science and Behavior Books.**

Fleischman, M. J., & Othmer, S. (2005). Case study: Improvements in IQ score and maintenance of gains following EEG biofeedback with mildly developmentally delayed twins. ***Journal of Neurotherapy*****, 9(4), 35-46.** This study reports on the improvements in IQ scores and maintenance of the gains following EEG biofeedback with identical twin girls with mild developmental delay and symptoms suggestive of Attention Deficit Hyperactivity Disorder (ADHD). Full Scale IQ scores increased 22 and 23 points after treatment and were maintained at three follow-up retests over a 52-month period. ADHD symptom checklists completed by their mother showed a similar pattern of improvement and maintenance of gains. The extent of improvement is supported by anecdotal reports of behavioral changes. The results are discussed in the context of other studies of EEG biofeedback also showing improved intelligence following EEG biofeedback.

Foks, M. (2005). Neurofeedback training as an educational intervention in a school setting: How the regulation of arousal states can lead to improved attention and behaviour in children with special needs. ***Educational & Child Psychology*****, 22(3), 67-77.** The current choice of treatment for the remediation of attentional and behavioural difficulties among primary school children with special educational needs (SEN) is, increasingly, pharmacological. If-neurofeedback can regulate brain arousal states and thereby improve attention, behaviour and readiness to learn, there may be a case for incorporating it into the special needs provision of mainstream primary schools, thus avoiding the use of potentially damaging stimulant medication as a means of controlling behaviour and promoting inclusion. An experimental design was used, employing the TOVA test as a pre-/post-test measure of attention and the TOVA rating scale as parental pre/post measure of behaviour, plus qualitative feedback as a post-treatment measure of attention/behaviour. Results indicate that neurofeedback may make an important impact on emotions and affect of the SEN individual, leading to improved behaviour and improved attentional capability; quality time spent on a no-failure task of any kind on a one-to-one basis may be beneficial to children with SEN, affecting their personal belief system and behaviour; incorporating neurofeedback as part of the school-based special needs provision is feasible and practicable

Fonseca LC, Tedrus GM, Bianchini MC & Silva TF. (2013). Electroencephalographic alpha reactivity on opening the eyes in children with attention-deficit hyperactivity disorder. *Clin EEG Neurosci.* 2013 Jan;44(1):53-7. doi: 10.1177/1550059412445659. The quantification of differences in alpha electroencephalograph (EEG) activity between the eyes-closed and eyes-open resting conditions could be used as a measure of resting state arousal. The objective of this study was to evaluate the contribution of EEG alpha reactivity on opening the eyes, to the neurophysiology of children with attention-deficit hyperactivity disorder (ADHD). Thirty-eight children with ADHD were assessed using quantitative EEG (qEEG) analysis of absolute band power at rest, with eyes open and closed. Alpha reactivity index was calculated on opening the eyes, defined from the relationship between the absolute powers in the respective bands in the periods with the eyes open and closed. EEG data of 38 sex- and age-matched controls, with no neurological or psychiatric problems, were collected for comparison. There was a significant reduction in absolute alpha power at all electrodes for both ADHD and control groups with eyes open, indicating an increase in the arousal level. However, the alpha reactivity index was greater, corresponding to less reactivity, in the frontal regions of the children with ADHD ($P < .01$). Such a finding suggests alterations in arousal mechanisms in ADHD. This research suggests that alpha reactivity on opening the eyes, allied with other variables from the qEEG, may improve diagnostic accuracy in ADHD.

Fritson, K. K., Wadkins, T. A., Gerdes, P., & Hof, D. (2007). The impact of neurotherapy on college students' cognitive abilities and emotions. *Journal of Neurotherapy*, 11(4), 1-9. Background. In past research, several case studies and five controlled-group studies explored the effect of electroencephalographic (EEG) biofeedback on intelligence, attention, and behavior in children diagnosed with attention deficit hyperactivity disorder, but no studies have explored the effects of EEG biofeedback in nonclinical adults on measures of response control, mood, emotional intelligence, and self-efficacy. Method. Sixteen nonclinical college students were randomly assigned to receive Beta/Sensory Motor Rhythm EEG biofeedback to increase 12 to 15 Hz activity while inhibiting 4 to 7 Hz and 22 to 36 Hz activity. A control group received placebo EEG biofeedback. All participants completed pre- and post measures assessing intelligence scores, attention, impulse control, mood, emotional intelligence, and self-efficacy to assess the effect of EEG biofeedback. Results. Results showed significant improvements in response control but no improvements in attention. Measures of intelligence and emotional functioning did not change after EEG biofeedback. Conclusions. This study indicates that response control may improve in a few as 20 EEG biofeedback sessions. Implications and shortcomings discussed.

Fuchs, T., Birbaumer, N., Lutzenberger, W., Gruzelier, J. H., & Kaiser, J. (2003). Neurofeedback treatment for attention deficit/hyperactivity disorder in children: A comparison with methylphenidate. *Applied Psychophysiology and Biofeedback*, 28, 1-12. Clinical trials have suggested that neurofeedback may be efficient in treating attention-deficit/hyperactivity disorder (ADHD). We compared the effects of a 3-month electroencephalographic feedback program providing reinforcement contingent on the production of cortical sensorimotor rhythm (12-15 Hz) and beta1 activity (15-18 Hz) with stimulant medication. Participants were N = 34 children aged 8-12 years, 22 of which were assigned to the neurofeedback group and 12 to the methylphenidate group according to their parents' preference. Both neurofeedback and methylphenidate were

associated with improvements on all subscales of the Test of Variables of Attention, and on the speed and accuracy measures of the d2 Attention Endurance Test. Furthermore, behaviors related to the disorder were rated as significantly reduced in both groups by both teachers and parents on the IOWA-Conners Behavior Rating Scale. These findings suggest that neurofeedback was efficient in improving some of the behavioral concomitants of ADHD in children whose parents favored a non-pharmacological treatment.

Gani C, Birbaumer N & Strehl U. (2008). Long term effects after feedback of slow cortical potentials and of theta-beta amplitudes in children with attention-deficit/hyperactivity disorder (ADHD). ***International Journal of Bioelectromagnetism*****, 10(4), 209-232.** Though it had already been shown in the 1970s that neurofeedback improves attention, academic performance and social behavior in children with ADHD, it has not been considered as a standard therapy so far. This is mainly due to the small number of controlled studies fulfilling methodological standards - especially long-term data was not available so far. We are the first to present long term data of children undergoing neurofeedback training. 47 patients in the age of 8 - 12 years were randomly assigned to two different training groups. One group was trained to self regulate slow cortical potentials (SCP), the other group tried to influence Theta- and Beta-amplitudes. Follow-up evaluation was carried out 6 months and more than 2 years after the last training session. Eleven children of the SCP group and 12 children of the Theta/Beta group took part in three booster sessions. Parents rated behavioral symptoms as well as frequency and impact of problems. Attention was measured with the Testbatterie zur Aufmerksamkeitsprüfung (TAP). All improvements in behavior and attention that had been observed at previous assessments turned out to be stable. Yet another significant reduction of number of problems and significant improvement in attention was observed. EEG-self regulation skills were preserved. In each group, half of the children no longer met ADHD criteria. 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.

Gevensleben H, Moll GH, Rothenberger A, Heinrich H. (2011). The usage of neurofeedback with children with ADHD: The method and its evaluation. ***Prax Kinderpsychol Kinderpsychiatr*****. 2011;60(8):666-76.** Neurofeedback is a computer-based behavior training, which is gaining increasing interest in the treatment of children with attention-deficit/hyperactivity disorder (ADHD). This article gives an introduction to neurofeedback and summarizes the state of research, discussing inter alia methodical aspects (e. g., requirements to a control training). Evaluation studies conducted so far indicate clinical efficacy. For example, neurofeedback training was superior to a computerized attention training in a randomized controlled trial (medium effect size). Follow-up investigations suggest that treatment effects remain stable (at least six months). At the clinical level, comparable improvements could be obtained for the neurofeedback protocols theta/beta training and training of slow cortical potentials. Neurophysiological findings document different mechanisms of theta/beta training and slow cortical potential training. Future studies should further elucidate the specificity of training effects related to the kind of training and certain disorders and address how to optimize and individualize neurofeedback training.

Gevensleben, H., Holl, B., Albrecht, B., Vogel, C., Schlamp, D., Kratz, O., Studer, P., Rothenberger, A., Moll, G. H. & Heinrich, H. (2009). Is neurofeedback an efficacious treatment for ADHD? A randomized

controlled clinical trial. ***The Journal of Child Psychology and Psychiatry*****; 74(2). 149-157.** In a randomized controlled trial, neurofeedback (NF) training was found to be superior to a computerized attention skills training concerning the reduction of ADHD symptomatology (Gevensleben et al., 2009). The aims of this investigation were to assess the impact of different NF protocols (theta/beta training and training of slow cortical potentials, SCPs) on the resting EEG and the association between distinct EEG measures and behavioral improvements. In 72 (of initially 102) children with ADHD, aged 8-12, EEG changes after either a NF training (n=46) or the control training (n=26) could be studied. The combined NF training consisted of one block of theta/beta training and one block of SCP training, each block comprising 18 units of 50 minutes (balanced order). Spontaneous EEG was recorded in a two-minute resting condition before the start of the training, between the two training blocks and after the end of the training. Activity in the different EEG frequency bands was analyzed. In contrast to the control condition, the combined NF training was accompanied by a reduction of theta activity. Protocol-specific EEG changes (theta/beta training: decrease of posterior-midline theta activity; SCP training: increase of central-midline alpha activity) were associated with improvements in the German ADHD rating scale. Related EEG-based predictors were obtained. Thus, differential EEG patterns for theta/beta and SCP training provide further evidence that distinct neuronal mechanisms may contribute to similar behavioral improvements in children with ADHD.

Ghaziri J, Tucholka A, Larue V, Blanchette-Sylvestre M, Reyburn G, Gilbert G, Lévesque J, Beauregard M. Neurofeedback Training Induces Changes in White and Gray Matter. Clin EEG Neurosci. 2013 Mar 26. The main objective of this structural magnetic resonance imaging (MRI) study was to investigate, using diffusion tensor imaging, whether a neurofeedback training (NFT) protocol designed to improve sustained attention might induce structural changes in white matter (WM) pathways, purportedly implicated in this cognitive ability. Another goal was to examine whether gray matter (GM) volume (GMV) might be altered following NFT in frontal and parietal cortical areas connected by these WM fiber pathways. Healthy university students were randomly assigned to an experimental group (EXP), a sham group, or a control group. Participants in the EXP group were trained to enhance the amplitude of their $\beta 1$ waves at F4 and P4. Measures of attentional performance and MRI data were acquired one week before (Time 1) and one week after (Time 2) NFT. Higher scores on visual and auditory sustained attention were noted in the EXP group at Time 2 (relative to Time 1). As for structural MRI data, increased fractional anisotropy was measured in WM pathways implicated in sustained attention, and GMV increases were detected in cerebral structures involved in this type of attention. After 50 years of research in the field of neurofeedback, our study constitutes the first empirical demonstration that NFT can lead to microstructural changes in white and gray matter.

Hammond, D. C. (2006). What is neurofeedback? ***Journal of Neurotherapy*****; 10(4). 25-36.** EEG biofeedback (neurofeedback) originated in the late 1960s as a method for retraining brainwave patterns through operant conditioning. Since that time a sizable body of research has accumulated on the effectiveness of neurofeedback in the treatment of uncontrolled epilepsy, ADD/ADHD, anxiety, alcoholism, posttraumatic stress disorder, and mild head injuries. Studies also provide encouraging indications that neurofeedback offers a treatment alternative for use with learning disabilities, stroke, depression, fibromyalgia, autism, insomnia,

tinnitus, headaches, problems with physical balance, and for the enhancement of peak performance. At a time when an increasing number of people are concerned with negative effects from relying solely on medication treatments, neurofeedback may offer an additional treatment alternative for many conditions. This article assists the reader to understand how neurofeedback works, how assessment allows neurofeedback to be individualized, and briefly reviews evidence for the neurofeedback treatment of many conditions. The public is cautioned that in selecting a practitioner for the treatment of the kinds of medical, psychiatric and psychological conditions cited above, a practitioner should be licensed for independent practice in their state or province and should ideally also be certified by a legitimately recognized body

Hansen, L. M., Trudeau, D., & Grace, L. (1996). Neurotherapy and drug therapy in combination for adult ADHD, personality disorder, and seizure. *Journal of Neurotherapy*, 2(1), 6-14. This is a case report of an adult female patient with ADHD, temporal seizure disorder, and Borderline Personality Disorder treated with 30 weekly sessions of SMR neurofeedback and carbamazepine. Posttreatment measures showed improvements in T.O.V.A., self-report, and QEEG. Both neurofeedback and carbamazepine showed the most effect in early treatment. Progress continued after discontinuance of the drug.

Helps, S., Broyd, SJ., James, CJ., Karl, A., Chen, W. & Sonuga-Barke, EJS. (2010). Altered spontaneous low frequency brain activity in attention deficit/hyperactivity disorder. Brain Research: Online February 2010. 134-143. Background: Resting brain activity appears altered in Attention Deficit/Hyperactivity Disorder (ADHD). The default mode interference hypothesis (Sonuga-Barke and Castellanos, 2007) postulates that patterns of spontaneous very low frequency brain activity, typical of the resting brain, cause attention lapses in ADHD when they remain unattenuated following the transition from rest to active task performance. Here we test this hypothesis using DC-EEG. Methods: DC-EEG recordings of very low frequency brain activity (<1.5 Hz) were compared for 16 male children with ADHD and 16 healthy controls during both rest and active task performance (two choice reaction time task). Results: A previously identified very low frequency resting network of electrodes was replicated. At rest ADHD children showed less EEG power in very low frequency bands (i.e., .02-.2 Hz). They also showed less attenuation of power at these frequency bands during rest-to-task transition. Reduced attenuation was associated with a number of measures of performance. Discussion: We confirmed the existence of altered very low frequency brain activity in ADHD. ADHD children may have deficits both in maintaining a resting brain when needed and 'protecting' an active brain from the intrusion of resting state brain activity.

Helps, S., James, C., Debener, S., Karl, A. & Sonuga-Barke, DJS. (2008). Very low frequency EEG oscillations and the resting brain in young adults: a preliminary study of localisation, stability and association with symptoms of inattention. *J Neural Transm*:115. 279-285. Background. Spontaneous very low frequency oscillations (VLFO: <0.2Hz) in functional magnetic-resonance imaging are proposed to identify a default-mode network of resting brain activity. Activity in this network has been related to lapses of attention during goal-directed tasks and may provide a basis for ADHD. This study assessed the relation between scalp-recorded EEG VLFO at rest and ADHD. Methods. 13 young adults with high- and 11 with low self-

ratings of ADHD participated. Direct current EEG was recorded during a five minute rest session and was retested after approximately 1 week. Results. A consistent and temporally stable pattern of VLFOs was observed across specific scalp regions in low-ADHD participants. High-ADHD participants had less VLFO power across these locations, especially where inattention self-ratings were high. Inattention was not related to VLFO power in other locations. Discussion. Initial evidence is provided for a pattern of VLFOs at rest which is associated with inattention symptoms.

Heinrich, H., Busch, K., Erbe, K., Moll, GH. & Kratz, O. (2014). EEG spectral analysis of attention in ADHD: implications for neurofeedback training. Frontiers of Human Neuroscience:21(8). 611. OBJECTIVE: In children with attention-deficit/hyperactivity disorder (ADHD), an increased theta/beta ratio in the resting EEG typically serves as a rationale to conduct theta/beta neurofeedback (NF) training. However, this finding is increasingly challenged. As NF may rather target an active than a passive state, we studied the EEG in a condition that requires attention. METHODS: In children with ADHD of the DSM-IV combined type (ADHD-C; N = 15) and of the predominantly inattentive type (ADHD-I; N = 9) and in typically developing children (N = 19), EEG spectral analysis was conducted for segments during the attention network test (ANT) without processing of stimuli and overt behavior. Frontal (F3, Fz, F4), central (C3, Cz, C4) and parietal (P3, Pz, P4) electrodes were included in the statistical analysis. To investigate if EEG spectral parameters are related to performance measures, correlation coefficients were calculated. RESULTS: Particularly in the ADHD-C group, higher theta and alpha activity was found with the most prominent effect in the upper-theta/lower-alpha (5.5-10.5 Hz) range. In the ADHD-I group, a significantly higher theta/beta ratio was observed at single electrodes (F3, Fz) and a tendency for a higher theta/beta ratio when considering all electrodes (large effect size). Higher 5.5-10.5 Hz activity was associated with higher reaction time variability with the effect most prominent in the ADHD-C group. A higher theta/beta ratio was associated with higher reaction times, particularly in the ADHD-I group. CONCLUSIONS: (1) In an attention-demanding period, children with ADHD are characterized by an underactivated state in the EEG with subtype-specific differences. (2) The functional relevance of related EEG parameters is indicated by associations with performance (reaction time) measures. (3) Findings provide a rationale for applying NF protocols targeting theta (and alpha) activity and the theta/beta ratio in subgroups of children with ADHD.

Hirshberg, L. M. (2007). Place of electroencephalographic biofeedback for attention deficit/hyperactivity disorder. ***Expert Review of Neurotherapeutics*****, 7(4), 315-319.** Historically, pharmacological treatments for attention-deficit/hyperactivity disorder (ADHD) have been considered to be the only type of interventions effective for reducing the core symptoms of this condition. However, during the past three decades, a series of case-and controlled-group studies examining the effects of EEG biofeedback have reported improved attention and behavioral control, increased cortical activation on quantitative electroencephalographic examination, and gains on tests of intelligence and academic achievement in response to this type of treatment. This review paper critically examines the empirical evidence, applying the efficacy guidelines jointly established by the Association for Applied Psychophysiology and Biofeedback (AAPB) and the International Society for Neuronal Regulation (ISNR). On the basis of these scientific principles, EEG biofeedback was

determined to be “probably efficacious” for the treatment of ADHD. Although significant clinical improvement was reported in approximately 75% of the patients in each of the published research studies, additional randomized, controlled group studies are needed in order to provide a better estimate of the percentage of patients with ADHD who will demonstrate such gains in clinical practice.

Holtman, M., Priewski, B., Wachtlin, D., Wolz, S. Strehl, U. (2014). Neurofeedback in children with attention deficit hyperactivity disorder (ADHD) - A controlled multicenter study of a non-pharmacological treatment approach. BMC Pediatr:14(202). BACKGROUND: Attention-deficit/hyperactivity disorder (ADHD) is the most common neurobehavioral disorder of childhood and has often a chronic course persisting into adulthood. However, up to 30% of children treated with stimulants either fail to show an improvement or suffer adverse side effects, including decreased appetite, insomnia and irritability and there is no evidence of long term efficacy of stimulants for ADHD. A series of studies has shown that neurofeedback is an effective additional or alternative treatment for children with ADHD, leading to e.g. significant and stable improvement in behavior, attention and IQ. Significant treatment effects of neurofeedback have also been verified in meta-analyses. Most of the trials, however, have been criticized for methodological difficulties, particularly lacking appropriate control conditions and number of patients included. This randomized study examines the efficacy of slow cortical potentials (SCP) -neurofeedback, controlling unspecific effects of the setting by comparing two active treatment modalities. METHODS/DESIGN: A total of 144 patients with ADHD, older than six and younger than ten years, in some cases with additional pharmacological treatment, are included in this trial. In five trial centres patients are treated either with SCP-feedback or electromyographic (EMG) -feedback in 25 sessions within 3 months. A comprehensive test battery is conducted before and after treatment and at follow-up 6 month later, to assess core symptoms of ADHD, general psychopathology, attentional performance, comorbid symptoms, intelligence, quality of life and cortical arousal. DISCUSSION: The efficacy of SCP-feedback training for children with ADHD is evaluated in this randomized controlled study. In addition to behavior ratings and psychometric tests neurophysiological parameters serve as dependent variables. Further, the choice of EMG-biofeedback as an active control condition is debated.

Hurt, E., Arnold, AE. & Lofthouse, N. (2014). Quantitative EEG neurofeedback for the treatment of pediatric attention-deficit hyperactivity disorder, autism spectrum disorders, learning disorders and epilepsy. Child and Adolescent Psychiatric Clinics of North America:23(3). 465-86. Neurofeedback (NF) using surface electroencephalographic signals has been used to treat various child psychiatric disorders by providing patients with video/audio information about their brain's electrical activity in real-time. Research data are reviewed and clinical recommendations are made regarding NF treatment of youth with attention deficit/hyperactivity disorder, autism, learning disorders, and epilepsy. Most NF studies are limited by methodological issues, such as failure to use or test the validity of a full-blind or sham NF. The safety of NF treatment has not been thoroughly investigated in youth or adults, although clinical experience suggests reasonable safety.

Jacobs, E. H. (2005). Neurofeedback treatment of two children with learning, attention, mood, social, and developmental deficits. *Journal of Neurotherapy*, 9(4), 55-70. Neurofeedback is biofeedback training of EEG activity through an operant conditioning process by which the individual strained to increase or inhibit the brain’s production of electrical activity in specific frequency ranges. Studies have demonstrated efficacy with a

variety of disorders, including attention deficit hyperactivity disorder (ADHD), learning problems, and autistic features. This paper describes the application of neurofeedback in a clinical setting with two complex children who manifested multiple diagnoses, including learning disabilities (LD), ADHD, social deficits, mood disorders, and pervasive developmental disorder (PDD). Both boys had adjusted poorly to school, family, and peers. Methods. Subjects were referred to the author's clinical practice. They received individualized protocols based on their symptoms and functional impairments. They were administered semi-weekly 20-minute sessions of one-channel neurofeedback training for approximately six months. In both cases symptoms were identified and tracked with a parent rating scale and one case, with the Symptom Assessment-45 Questionnaire (SA-45) also.

Janssen, TW., Bink, M., Gelade, K., van Mourik, R., Maras, A. & Oosterlaan, J. (2016). A randomized controlled trial into the effects of neurofeedback, methylphenidate, and physical activity on EEG power spectra in children with ADHD. J. Child Psychology and Psychiatry: doi10.1111/jcpp.12517. Background: The clinical and neurophysiological effects of neurofeedback (NF) as treatment for children with ADHD are still unclear. This randomized controlled trial (RCT) examined electroencephalogram (EEG) power spectra before and after NF compared to methylphenidate (MPH) treatment and physical activity (PA) - as semi-active control group - during resting and active (effortful) task conditions to determine whether NF can induce sustained alterations in brain function. Methods: Using a multicentre three-way parallel group RCT design, 112 children with a DSM-IV diagnosis of ADHD, aged between 7 and 13 years, were initially included. NF training consisted of 30 sessions of theta/beta training at Cz over a 10-week period. PA training was a semi-active control group, matched in frequency and duration. Methylphenidate was titrated using a double-blind placebo controlled procedure in 6 weeks, followed by a stable dose for 4 weeks. EEG power spectra measures during eyes open (EO), eyes closed (EC) and task (effortful) conditions were available for 81 children at pre- and post intervention (n = 29 NF, n = 25 MPH, n = 27 PA). Clinical trials registration: Train Your Brain? Exercise and Neurofeedback Intervention for ADHD, https://clinicaltrials. gov/show/NCT01363544, Ref. No. NCT01363544. Results: Both NF and MPH resulted in comparable reductions in theta power from pre- to postintervention during the EO condition compared to PA (gp2 = .08 and .12). For NF, greater reductions in theta were related to greater reductions in ADHD symptoms. During the task condition, only MPH showed reductions in theta and alpha power compared to PA (gp2 = .10 and .12). Conclusions: This study provides evidence for specific neurophysiological effects after theta/beta NF and MPH treatment in children with ADHD. However, for NF these effects did not generalize to an active task condition, potentially explaining reduced behavioural effects of NF in the classroom. Keywords: ADHD; neurofeedback; methylphenidate; physical activity; EEG; RCT.

Kaiser, D. A., & Othmer, S. (2000). Effect of Neurofeedback on variables of attention in a large multi-center trial. *Journal of Neurotherapy*, 4(1), 5-15. Since the first reports of Neurofeedback treatment in ADHD in 1976 many studies have been carried out investigating the effects of Neurofeedback on different symptoms of ADHD such as inattention, impulsivity and hyperactivity. This technique is also used by many practitioners, but the question as to the evidence-based level of this treatment is still unclear. In this study selected

research on Neurofeedback treatment for ADHD was collected and a meta-analysis was performed. Both prospective controlled studies and studies employing a pre- and post-design found large effect sizes (ES) for Neurofeedback on impulsivity and inattention and a medium ES for hyperactivity. Randomized studies demonstrated a lower ES for hyperactivity suggesting that hyperactivity is probably most sensitive to non-specific treatment factors. Due to the inclusion of some very recent and sound methodological studies in this meta-analysis potential confounding factors such as small studies, lack of randomization in previous studies and a lack of adequate control groups have been addressed and the clinical effects of Neurofeedback in the treatment of ADHD can be regarded as clinically meaningful. Four randomized controlled trials have shown Neurofeedback to be superior to a (semi- active) control group, whereby the requirements for Level 4: Efficacious are fulfilled (Criteria for evaluating the level of evidence for efficacy established by the AAPB and ISNR). Three studies have employed a semi-active control group, which can be regarded as a credible sham control providing an equal level of cognitive training and client-therapist interaction. Therefore, in line with the AAPB and ISNR guidelines for rating clinical efficacy, we conclude that Neurofeedback treatment for ADHD can be considered 'Efficacious and Specific' (Level 5) with a large ES for inattention and impulsivity and a medium ES for hyperactivity.

Karch, S., Loy, F., Krause, D., Schwartz, S., Kiesewetter, J., Segmiller, F., Chrobok, A., Keeser, D. & Pogarell, O. (2016). Increased event-related potentials and alpha-, beta-, and gamma-activity associated with intentional actions. Frontiers in Psychology: January doi: 10.3389/fpsyg.2016.00007. Objective: Internally -guided actions are defined as being purposeful, self-generated and offering choices between alternatives. Intentional actions are essential to reach individual goals. In previous empirical studies, internally guided actions were predominantly related to functional responses in frontal and parietal areas. The aim of the present study was to distinguish event-related potentials and oscillatory responses of intentional actions and externally guided actions. In addition, we compared neurobiological findings of the decision which action to perform with those referring to the decision whether or not to perform an action. Methods: Twenty-eight subjects participated in adapted go/nogo paradigms, including a voluntary selection condition allowing participants to (1) freely decide whether to press the response button or (2) to decide whether they wanted to press the response button with the right index finger or the left index finger. Results: The reaction times were increased when participants freely decided whether and how they wanted to respond compared to the go condition. Intentional processes were associated with a fronto-centrally located N2 and P3 potential. N2 and P3 amplitudes were increased during intentional actions compared to instructed responses (*go*). In addition, increased activity in the alpha-, beta- and gamma-frequency range was shown during voluntary behavior rather than during externally guided responses. Conclusion: These results may indicate that an additional cognitive process is needed for intentional actions compared to instructed behavior. However, the neural responses were comparatively independent of the kind of decision that was made (1) decision which action to perform; (2) decision whether or not to perform an action). Significance: The study demonstrates the importance of fronto-central alpha-, beta-, and gamma oscillations for voluntary behavior.

Kerson C; Collaborative Neurofeedback Group. (2013). A Proposed Multisite Double-Blind Randomized Clinical Trial of Neurofeedback for ADHD: Need, Rationale, and Strategy. J Atten

Disord. 2013 Jul;17(5):420-36. doi: 10.1177/1087054713482580. Epub:Apr 16. Objective: Additional treatments with persisting benefit are needed for ADHD. Because ADHD often shows excessive theta electroencephalogram (EEG) power, low beta, and excessive theta-beta ratio (TBR), a promising treatment is neurofeedback (NF) downtraining TBR. Although several nonblind randomized clinical trials (RCTs) show a medium-large benefit for NF, a well-blinded, sham-controlled RCT is needed to differentiate specific from nonspecific effects. Method: Experts in NF, ADHD, clinical trials, and statistics collaborated to design a double-blind multisite RCT. Results/Conclusion: At four sites, 180 children aged 7 to 10 years with rigorously diagnosed ADHD and TBR ≥ 5 will be randomized to active TBR-NF versus sham NF of equal duration, intensity, and appearance. Sham, utilizing prerecorded EEGs with participant artifacts superimposed, will keep participants and staff blind. Treatment fidelity will be trained/monitored by acknowledged NF leaders. Multidomain assessments before, during, and after treatment (follow-up to 2 years) will also include tests of blinding and sham inertness.

Kirk, L. (2007). *Neurofeedback protocols for subtypes of attention deficit/hyperactivity disorder*. Chapter in J. R. Evans (Ed.), Handbook of Neurofeedback. Binghampton, NY: Haworth Medical Press, pp. 267-299.

Kropotov, J. D., Grin-Yatsenko, V. A., Ponomarev, V. A., Chutko, L. S., Yakovenko, E. A., & Nikishena, I. S. (2007). Changes in EEG spectograms, event-related potentials and event-related desynchronization induced by relative beta training in ADHD children. *Journal of Neurotherapy*, 11(2), 3-11. Attention-deficit/hyperactivity disorder (ADHD) is a developmental disorder that, by current definition, has onset prior to age 7 years. MRI studies have provided some insight into brain differences associated with ADHD, but thus far have almost exclusively focused on children ages 7 years and older. To better understand the neurobiological development of ADHD, cortical and subcortical brain development should be systematically examined in younger children presenting with symptoms of the disorder. High-resolution anatomical (MPRAGE) images, acquired on a 3.0T scanner, were analyzed in a total of 26 preschoolers, ages 4-5 years (13 with ADHD, 13 controls, matched on age and sex). The ADHD sample was diagnosed using DSM-IV criteria, and screened for language disorders. Cortical regions were delineated and measured using automated methods in Freesurfer; basal ganglia structures were manually delineated. Children with ADHD showed significantly reduced caudate volumes bilaterally; in contrast there were no significant group differences in cortical volume or thickness in this age range. After controlling for age and total cerebral volume, left caudate volume was a significant predictor of hyperactive/impulsive, but not inattentive symptom severity. Anomalous basal ganglia, particularly caudate, development appears to play an important role among children presenting with early onset symptoms of ADHD.

Kropotov, J. D., Grin-Yatsenko, V. A., Ponomarev, V. A., Chutko, L. S., Yakovenko, E. A., Nildshena, I. S. (2005). ERP correlates of EEG relative beta training in ADHD children. *International Journal of Psychophysiology*, 55(1), 23-34. Eighty-six children (ages9-14)with attention deficit hyperactivity disorder (ADHD) participated in this study. Event-related potentials (ERPs) were recorded in auditory GO/NOGO task before and after15-22 sessions of EEG biofeedback. Each session consisted of 20 min of enhancing the ratio of the EEG power in15-18 Hz band to the EEG power in the rest of spectrum, and 7-10 min of enhancing of

the ratio of the EEG power in12-15 Hz to the EEG power in the rest of spectrum with C3-Fz electrodes' placements for the first protocol and C4-Pz for the second protocol. On the basis of quality of performance during training sessions, the patients were divided into two groups: good performers and bad performers. ERPs of good performers to GO and NOGO cues gained positive components evoked within180-420ms latency. At the same time, no statistically significant differences between pre- and post-training ERPs were observed for bad performers. The ERP differences between post- and pre treatment conditions for good performers were distributed over frontal-central areas and appear to reflect an activation of frontal cortical areas associated with beta training.

Kraus, D., Folkerts, M., Karch, S., Keeser, D., Chrobok, A., Zaudig, M., Hergerl, U., Juckel, G. & Pogarel, O. (2016). Prediction of treatment outcome in patients with obsessive-compulsive disorder with low-resolution brain electromagnetic tomography: A prospective study. Frontiers in Psychology: January doi: 10.3389/fpsyg.2015.01993. The issue of predicting treatment response and identifying, in advance, which patient will profit from treating obsessive-compulsive disorder (OCD) seems to be an elusive goal. This prospective study investigated brain electric activity [using Low-Resolution Brain Electromagnetic Tomography (LORETA)] for the purpose of predicting response to treatment. Forty-one unmedicated patients with a DSM-IV diagnosis of OCD were included. A resting 32-channel EEG was obtained from each participant before and after 10 weeks of standardized treatment with sertraline and behavioral therapy. LORETA was used to localize the sources of brain electrical activity. At week 10, patients were divided into responders and non-responders (according to a reduction of symptom severity >50% on the Y-BOCS). LORETA analysis revealed that at baseline responders showed compared to non-responders a significantly lower brain electric activity within the beta 1 (t = 2.86, p < 0.05), 2 (t = 2.81, p < 0.05), and 3 (t = 2.76, p < 0.05) frequency bands and ROI analysis confirmed a reduced activity in alpha 2 (t = 2.06, p < 0.05) in the anterior cingulate cortex (ACC). When baseline LORETA data were compared to follow-up data, the analysis showed in the responder group a significantly lower brain electrical resting activity in the beta 1 (t = 3.17. p < 0.05) and beta 3 (t = 3.11. p < 0.05) frequency bands and equally for the ROI analysis of the orbitofrontal cortex (OFC) in the alpha 2 (t = 2.15. p < 0.05) frequency band. In the group of non-responders the opposite results were found. In addition, a positive correlation between frequency alpha 2 (rho = 0.40, p = 0.010), beta 3 (rho = 0.42, p = 0.006), delta (rho = 0.33, p = 0.038), theta (rho = 0.34, p = 0.031), alpha 1 (rho = 0.38, p = 0.015), and beta1 (rho = 0.34, p = 0.028) of the OFC and the bands delta (rho = 0.33, p = 0.035), alpha 1 (rho = 0.36, p = 0.019), alpha 2 (rho = 0.34, p = 0.031), and beta 3 (rho = 0.38, p = 0.015) of the ACC with a reduction of the Y-BOCS scores was identified. Our results suggest that measuring brain activity with LORETA could be an efficient and applicable technique to prospectively identify treatment responders in OCD.

Kwon, H., Cho, J., Lee, E. (2009). EEG asymmetry analysis of the left and right brain activities during simple versus complex arithmetic learning. *Journal of Neurotherapy* 13(2), 109 - 116. Repeated practice of simple arithmetic such as addition, subtraction, and multiplication has been widely used for effective math education. Brain activity patterns during simple and complex arithmetic calculation have been explored by several research groups using magnetic resonance images (MRI) and functional MRI (fMRI), and some have

reported that the balanced whole brain (both left andright brain) activities during simple arithmetic in contrast to the predominant left brain activities during complex arithmetic. Methods. In this work, we have identified the characteristic brainwaves and asymmetric activation patterns of the left and right brain during the process of simple and complex arithmetic by measuring theta, alpha, Sensory Motor Response (SMR), and beta brainwaves of 24 participants from the location FP1 (left brain) and FP2 (right brain) using EEG. Results. Simple statistics analysis showed the significantly different beta activities from the left brain during complex arithmetic compared to simple arithmetic process, and through the asymmetry analysis of the left and right brain activities, less symmetrical brain activation during complex calculation, that is, specifically higher SMR, and beta brainwaves in the left hemisphere more than right hemisphere was identified, which is consistent with recent fMRI findings. Conclusion. The results imply that simple arithmetic process may improve the whole brain activities in a balanced way while complex arithmetic induce unbalanced activities of the left and right brain.

Leins, U., Goth, G., Hinterberger, T., Klinger, C., Rumpf, M., & Strehl, U. (2007). Neurofeedback for children with ADHD: A comparison of SCP and theta/beta protocols. ***Applied Psychophysiology & Biofeedback*****, 32.** Behavioral and cognitive improvements in children with ADHD have been consistently reported after neurofeedback treatment. However, neurofeedback has not been commonly accepted as a treatment for ADHD. This study addresses previous methodological shortcomings while comparing a neurofeedback training of Theta-Beta frequencies and training of slow cortical potentials (SCPs). The study aimed at answering (a) whether patients were able to demonstrate learning of cortical self-regulation, (b) if treatment leads to an improvement in cognition and behavior and (c) if the two experimental groups differ in cognitive and behavioral outcome variables. SCP participants were trained to produce positive and negative SCP-shifts while the Theta/Beta participants were trained to suppress Theta (4-8 Hz) while increasing Beta (12-20 Hz). Participants were blind to group assignment. Assessment included potentially confounding variables. Each group was comprised of 19 children with ADHD (aged 8-13 years). The treatment procedure consisted of three phases of 10 sessions each. Both groups were able to intentionally regulate cortical activity and improved in attention and IQ. Parents and teachers reported significant behavioral and cognitive improvements. Clinical effects for both groups remained stable six months after treatment. Groups did not differ in behavioural or cognitive outcome.

Leins, U., Goth, G., Hinterberger, T., Klinger, C., Rumpf, N., & Strehl, U. (2007). Neurofeedback for children with ADHD: A comparison of SCP and theta/beta protocols. ***Applied Psychophysiology & Biofeedback*****, 32(2), 73-88.** Behavioral and cognitive improvements in children with ADHD have been consistently reported after neurofeedback-treatment. However, neurofeedback has not been commonly accepted as a treatment for ADHD. This study addresses previous methodological shortcomings while comparing a neurofeedback-training of Theta-Beta frequencies and training of slow cortical potentials (SCPs). The study aimed at answering (a) whether patients were able to demonstrate learning of cortical self-regulation, (b) if treatment leads to an improvement in cognition and behavior and (c) if the two experimental groups differ in cognitive and behavioral outcome variables. SCP participants were trained to produce positive and negative

SCP-shifts while the Theta/Beta participants were trained to suppress Theta (4-8 Hz) while increasing Beta (12-20 Hz). Participants were blind to group assignment. Assessment included potentially confounding variables. Each group was comprised of 19 children with ADHD (aged 8-13 years). The treatment procedure consisted of three phases of 10 sessions each. Both groups were able to intentionally regulate cortical activity and improved in attention and IQ. Parents and teachers reported significant behavioral and cognitive improvements. Clinical effects for both groups remained stable six months after treatment. Groups did not differ in behavioural or cognitive outcome.

Lenartowitz, A., Delorme, A., Walshaw, PD., Cho, AL., Bilder, RM., McGough, JJ., McCracken, JT., Makeaig, S & Loo, S. (2014). Electroencephalography Correlates of Spatial Working Memory Deficits in Attention-Deficit/Hyperactivity Disorder: Vigilance, Encoding, and Maintenance. Journal of Neuroscience:34(4). 1171-1182. In the current study we sought to dissociate the component processes of working memory (WM) (vigilance, encoding and maintenance) that may be differentially impaired in attention-deficit/ hyperactivity disorder (ADHD). We collected electroencephalographic (EEG) data from 52 children with ADHD and 47 typically developing (TD) children, ages 7-14 years, while they performed a spatial Sternberg working memory task. We used independent component analysis and time-frequency analysis to identify midoccipital alpha (8 -12 Hz) to evaluate encoding processes and frontal midline theta (4 -7 Hz) to evaluate maintenance processes. We tested for effects of task difficulty and cue processing to evaluate vigilance. Children with ADHD showed attenuated alpha band event-related desynchronization (ERD) during encoding. This effect was more pronounced when task difficulty was low (consistent with impaired vigilance) and was predictive of memory task performance and symptom severity. Correlated with alpha ERD during encoding were alpha power increases during the maintenance period (relative to baseline), suggesting a compensatory effort. Consistent with this interpretation, midfrontal theta power increases during maintenance were stronger in ADH D and in high-load memory conditions. Furthermore, children with ADHD exhibited a maturational lag in development of posterior alpha power whereas age-related changes in frontal theta power deviated from the TD pattern. Last, subjects with ADHD showed age-independent attenuation of evoked responses to warning cues, suggesting low vigilance. Combined, these three EEG measures predicted diagnosis with 70% accuracy. We conclude that the interplay of impaired vigilance and encoding in ADHD may compromise maintenance and lead to impaired WM performance in this group.

Levesque, J., Beauregard, M., & Mensour, B. (2006). Effect of neurofeedback training on the neural substrates of selective attention in children with attention-deficit/hyperactivity disorder: a functional magnetic resonance imaging study. *Neuroscience Letters*, 394(3), 216-221. Attention Deficit Hyperactivity Disorder (AD/HD) is a neurodevelopmental disorder mainly characterized by impairments in cognitive functions. Functional neuroimaging studies carried out in individuals with AD/HD have shown abnormal functioning of the anterior cingulate cortex (ACC) during tasks involving selective attention. In other respects, there is mounting evidence that neurofeedback training (NFT) can significantly improve cognitive functioning in AD/HD children. In this context, the present functional magnetic resonance imaging (fMRI) study was conducted to measure the effect of NFT on the neural substrates of selective attention in children with AD/HD. Twenty AD/HD children– not taking any psychostimulant and without co-morbidity-participated to the study. Fifteen children were

randomly assigned to the Experimental (EXP) group (NFT), whereas the other five children were assigned to the Control (CON) group (no NFT). Subjects from both groups were scanned 1 week before the beginning of the NFT (Time 1) and 1 week after the end of this training (Time 2), while they performed a Counting Stroop task. At Time 1, for both groups, the Counting Stroop task was associated with significant loci of activation in the left superior parietal lobule. No activation was noted in the ACC. At Time 2, for both groups, the Counting Stroop task was still associated with significant activation of the left superior parietal lobule. This time, however, for the EXP group only there was a significant activation of the right ACC. These results suggest that in AD/HD children, NFT has the capacity to normalize the functioning of the ACC, the key neural substrate of selective attention.

Linden, M., Habib, T., & Radojevic, V. (1996). A controlled study of the effects of EEG biofeedback on cognition and behavior of children with attention deficit disorder and learning disabilities. *Biofeedback & Self-Regulation*, 21(1), 35-49. Eighteen children with ADD/ADHD, some of whom were also LD, ranging in ages from 5 through 15 were randomly assigned to one of two conditions. The experimental condition consisted of 40 45-minute sessions of training in enhancing beta activity and suppressing theta activity, spaced over 6 months. The control condition, waiting list group, received no EEG biofeedback. No other psychological treatment or medication was administered to any subjects. All subjects were measured at pretreatment and at posttreatment on an IQ test and parent behavior rating scales for inattention, hyperactivity, and aggressive/defiant (oppositional) behaviors. At posttreatment the experimental group demonstrated a significant increase (mean of 9 points) on the K-Bit IQ Composite as compared to the control group ($p < .05$). The experimental group also significantly reduced inattentive behaviors as rated by parents ($p < .05$). The significant improvements in intellectual functioning and attentive behaviors might be explained as a result of the attentional enhancement affected by EEG biofeedback training. Further research utilizing improved data collection and analysis, more stringent control groups, and larger sample sizes are needed to support and replicate these findings.

Lofthouse N, Arnold LE, Hersch S, Hurt E, DeBeus R. (2011). A review of neurofeedback for pediatric ADHD. *Journal of Attention Disorders*; 16(5). 351-372. The aim of this paper was to review all randomized published trials and unpublished conference presentations on the neurofeedback (NF) treatment of pediatric ADHD, and their relevance, strengths, and limitations. METHOD: Via PsychInfo and Medline searches and contacts with NF researchers 14 studies were identified and reviewed. RESULTS: The majority were conducted from 1994 to 2010, with 5- to 15-year-olds, usually male and White with the combined type of ADHD. Most studies used theta/beta NF with a unipolar-electrode placement at Cz and demonstrated, where reported, an overall ADHD mean effect size of d = 0.69, a medium effect. Main study strengths, within some studies, include use of randomization, treatment control conditions, Diagnostic and Statistical Manual of Mental Disorders criteria, evidence-based assessment of ADHD, standard treatment outcome measures, multi-domain assessment, and, for some studies, moderate sample size, some type of blind and the identification of medication as a concomitant treatment. Main study limitations (and directions for future research) include the lack of adequate blinding of participants, raters and NF trainers, a sham-NF/blinded control treatment

condition, post treatment follow-up, generalizability, specific details about delivery of NF, identification and control of comorbidity, and the identification, measurement, and control of concomitant treatments and potential side effects. CONCLUSION: Based on the results and methodologies of published studies, this review concludes that NF for pediatric ADHD can be currently considered as "probably efficacious."

Loo, S., & Barkley, R. (2005). Clinical utility of EEG in attention deficit hyperactivity disorder. ***Applied Neuropsychology*****, 12(2), 64-76.** Electrophysiological measures were among the first to be used to study brain processes in children with attention deficit hyperactivity disorder (ADHD; Diagnostic and Statistical Manual of Mental Disorders [4th ed.], American Psychiatric Association, 1994) and have been used as such for over 30 years (see Hastings & Barkley, 1978, for an early review). More recently, electroencephalography (EEG) has been used both in research to describe and quantify the underlying neurophysiology of ADHD, but also clinically in the assessment, diagnosis, and treatment of ADHD. This review will first provide a brief overview of EEG and then present some of the research findings of EEG correlates in ADHD. Then, the utility of EEG in making an ADHD diagnosis and predicting stimulant response will be examined. Finally, and more controversially, we will review the results of the most recent studies on EEG biofeedback (neurofeedback) as a treatment for ADHD and the issues that remain to be addressed in the research examining the efficacy this therapeutic approach.

Lubar, J. F. (2003). ***Neurofeedback for the management of attention-deficit / hyperactivity disorders*****. Chapter in M. S. Schwartz & F. Andrasik (Eds.), Biofeedback: A Practitioner's Guide (Third Edition. New York, Guilford, 409-437.**

Lubar, J. O., & Lubar, J. F. (1984). Electroencephalographic biofeedback of SMR and beta for treatment of attention deficit disorders in a clinical setting. ***Biofeedback & Self-Regulation*****, 9, 1-23.** Six children were provided with long-term biofeedback and academic treatment for attention deficit disorders. Their symptoms were primarily learning disabilities, and, in some cases, there were varying degrees of hyperkinesis. The training consisted of two sessions per week for ten to 27 months, with a gradual phase-out. Feedback was provided for either increasing 12-15 Hz SMR or 16-20 beta activity. Inhibit circuits were employed for SMR or beta when either gross movement excessive EMG, or theta (4-8 HZ) activity was present. Treatment also consisted of combining the biofeedback with academic training, including reading, arithmetic and spatial tasks to improve their attention. All children increased SMR or beta and decreased slow EEG and EMG activity. Changes could be seen in their power spectra after training in terms of increased beta and decreased slow activity. All six children demonstrated considerable improvement in their schoolwork in terms of grades or achievement test scores. None of the children are currently on any medications for hyperkinetic behavior. The results indicate that EEG biofeedback training, if applied comprehensively, can be highly effective in helping to remediate children who are experiencing attention deficit disorders.

Lubar, J. F., & Shouse, M. N. (1976). EEG and behavioral changes in a hyperactive child concurrent with training of the sensorimotor rhythm (SMR): A preliminary report. ***Biofeedback & Self-Regulation*****, 1(3), 293-306.** Reduced seizure incidence coupled with voluntary motor inhibition accompanied conditioned increases in the sensorimotor rhythm (SMR), a 12-14 Hz rhythm appearing over rolandic cortex. Although SMR biofeedback

training has been successfully applied to various forms of epilepsy in humans, its potential use in decreasing hyperactivity has been limited to a few cases in which a seizure history was also a significant feature. The present study represents a first attempt to explore the technique's applicability to the problem of hyperkinesis independent of the epilepsy issue. The results of several months of EEG biofeedback training in a hyperkinetic child tend to corroborate and extend previous findings. Feedback presentations for SMR were contingent on the production of 12-14-Hz activity in the absence of 4- 7-Hz slow-wave activity. A substantial increase in SMR occurred with progressive SMR training and was associated with enhanced motor inhibition, as gauged by laboratory measures of muscular tone (chin EMG) and by a global behavioral assessment in the classroom. Opposite trends in motor inhibition occurred when the training procedure was reversed and feedback presentations were contingent on the production of 4-7 Hz in the absence of 12-14-Hz activity. Although the preliminary nature of these results is stressed, the subject population has recently been increased to establish the validity and generality of the findings and will include the use of SMR biofeedback training after medication has been withdrawn.

Lubar, J. F., Swartwood, M. O., Swartwood, J. N., & O'Donnell, P. H. (1995). Evaluation of the effectiveness of EEG neurofeedback training for ADHD in a clinical setting as measured by changes in T.O.V.A., scores, behavioral ratings, and WISC-R performance. *Biofeedback & Self-Regulation*, 20(1), 83-99. A study with three component parts was performed to assess the effectiveness of neurofeedback treatment for Attention Deficit/Hyperactivity Disorder (ADHD). The subject pool consisted of 23 children and adolescents ranging in age from 8 to 19 years with a mean of 11.4 years who participated in a 2-to 3-month summer program of intensive neurofeedback training. Feedback was contingent on the production of 16-20 hertz (beta) activity in the absence of 4-8 hertz (theta) activity. Posttraining changes in EEG activity, T.O.V~I. performance, (ADDES) behavior ratings, and WISC-R performance were assessed. Part I indicated that subjects who successfully decreased theta activity showed significant improvement in T.O. VM. performance; Part II revealed significant improvement in parent ratings following neurofeedback training; and Part III indicated significant increases in WISC-R scores following neurofeedback training. This study is significant in that it examines the effects of neurofeedback training on both objective and subjective measures under relatively controlled conditions. Out findings corroborate and extend previous research, indicating that neurofeedback training can be an appropriate and efficacious treatment for children with ADHD.

Lutzenberger W, Elbert T, Rockstroh B, Birbaumer N. (1982) Biofeedback produced slow brain potentials and task performance. *Biological Psychology*, 14, 99-111. Twenty subjects learned to control slow potential (SP) shifts of the brain by means of a biofeedback procedure. Depending upon the pitch of a signal tone, negative SP shifts had to be increased or reduced during intervals of 6 sec each. Visual feedback of the actual SP shift was given. Blocks of training trials alternated with blocks of test trials without any feedback of the SPs. At the end of every test trial a simple arithmetic problem had to be solved by the subjects. Subjects performed the computation in a shorter time interval if an increased negativity preceded task onset as compared to slower response times during suppression of negativity. Results suggest that cortical negativity reflects unspecific preparation for cerebral performance.

Maurizio, S., Liechti, MD., Heinrich, H., Jancke, L., Steinhausen, HC., Walitza, S., Brandeis, D. & Drechsler, R. (2014). Comparing tomographic EEG neurofeedback and EMG biofeedback in children with attention-deficit hyperactivity disorder. Biological Psychology:Jan:95 31-44. Two types of biofeedback (BF), tomographic electroencephalogram (EEG) neurofeedback (NF) and electromyographic biofeedback (EMG-BF), both with phasic and tonic protocols, were compared for treatment effects and specificity in attention-deficit/hyperactivity disorder (ADHD). Thirteen children with ADHD trained their brain activity in the anterior cingulate cortex (ACC), and twelve trained activity of arm muscles involved in fine motor skills. In each training session, resting state 24-channel EEG and training performances were recorded. Both groups showed similar behavioral improvements and artifact reduction in selected conditions, with no significant advantages despite medium effect sizes on primary outcomes for NF. Only the EMG-BF group, however, showed clear improvement in training regulation performance, and specific motor coordination effects. The NF group tended to present individual normalization of trained frequency bands in the ACC during rest across training. The results provide evidence for some specific effects in our small sample, albeit only to a small extent.

Mayer, K., Blume, F., Wyckoff, SN., Brokmeier, LL. & Strehl, U. (2015). Neurofeedback of slow cortical potentials as a treatment for adults with Attention Deficit-/Hyperactivity Disorder. Objective: Attention Deficit-/Hyperactivity Disorder (ADHD) has been treated successfully in children with neurofeedback (NF). In this study, for the first time NF is investigated in adults with ADHD. To answer the question of specificity the relationship between treatment outcome and self-regulation ability is assessed. Methods: Twenty-four participants underwent 30 sessions of slow cortical potential NF. Measurements of ADHD and comorbid symptoms, as well as neurophysiological data (reaction time (RT) and RT variability (RTV) and contingent negative variation (CNV)) were performed before and after treatment, and again six months after sessions were completed. Participants were categorized into self-regulation learners and non-learners. Results: Significant improvements on all symptom scales were observed with medium to large effect sizes after treatment and six months post treatment. RT and RTV decreased significantly and there was a trend for an increased CNV. Half of the participants successfully learned to regulate their brain activity. In the long-term, symptoms in the group of learners improved more than in non-learners with large effect sizes. Conclusion: NF is effective in treating adult ADHD long-term. The impact of self-regulation ability and possible unspecific effects still require further investigation. Significance: This study is the first to investigate the effects of NF in adults with ADHD, relating clinical outcome to self-regulation performance.

Mayer K, Wyckoff SN, Strehl U.(2013).One size fits all? Slow cortical potentials neurofeedback: a review. J Atten Disord. 2013 Jul;17(5):393-409. doi: 10.1177/1087054712468053. Epub 2012 Dec 20. *Objective:* The intent of this manuscript was to review all published studies on slow cortical potentials (SCP) neurofeedback for the treatment of ADHD, with emphasis on neurophysiological rationale, study design, protocol, outcomes, and limitations. *Method*: For review, PubMed, MEDLINE, ERIC, and Google Scholar searches identified six studies and six subsequent publications. In addition to five studies focusing on children with Diagnostic and Statistical Manual of Mental Disorders (4th ed.; DSM-IV)-diagnosed ADHD, one study reports on adults. *Results*: SCP protocols utilize unipolar-electrode placement at Cz, randomized bidirectional signal regulation, feedback/transfer trials, and discrete feedback/rewards. Results demonstrated learning of SCP

self-regulation, moderate to large within group effect sizes for core ADHD symptom reduction, and enhancement of event-related potentials/electroencephalogram components. Neurophysiological and session variables were predictive of treatment outcome, but open questions of specific and nonspecific effects remain. Study limitations and future directions are discussed. *Conclusion*: SCP is an efficacious and standardized neurofeedback protocol that addresses behavioral and neurophysiological deficits in ADHD.

Miskovic, V., Ma, X., Chou, C., Fan, M., Owens, M., Sayama, H. & Gibb, BE. (2015). Development changes in spontaneous electrical activity and network organization from early to late childhood. NeuroImage: 118. 237-247. We investigated the development of spontaneous (resting state) cerebral electric fields and their network organization from early to late childhood in a large community sample of children. Critically, we examined electrocortical maturation across one-year windows rather than creating aggregate averages that can miss subtle maturational trends. We implemented several novel methodological approaches including a more fine grained examination of spectral features across multiple electrodes, the use of phase-lagged functional connectivity to control for the confounding effects of volume conduction and applying topological network analyses to weighted cortical adjacency matrices. Overall, there were major decreases in absolute EEG spectral density (particularly in the slow wave range) across cortical lobes as a function of age. Moreover, the peak of the alpha frequency increased with chronological age and there was a redistribution of relative spectral density toward the higher frequency ranges, consistent with much of the previous literature. There were age differences in long range functional brain connectivity, particularly in the alpha frequency band, culminating in the most dense and spatially variable networks in the oldest children. We discovered age-related reductions in characteristic path lengths, modularity and homogeneity of alpha-band cortical networks from early to late childhood. In summary, there is evidence of large scale reorganization in endogenous brain electric fields from early to late childhood, suggesting reduced signal amplitudes in the presence of more functionally integrated and band limited coordination of neuronal activity across the cerebral cortex.

Monastra, V. J., (2005). Electroencephalographic biofeedback (neurotherapy) as a treatment for attention deficit hyperactivity disorder: Rationale and empirical foundation. *Child & Adolescent Psychiatric Clinics of North America*, 14(1), 55-82. During the past three decades, electroencephalographic (EEG) biofeedback has emerged as a nonpharmacologic treatment for attention-deficit/hyperactivity disorder (ADHD). This intervention was derived from operant conditioning studies that demonstrated capacity for neurophysiologic training in humans and other mammals and targets atypical patterns of cortical activation that have been identified consistently in neuroimaging and quantitative EEG studies of patients diagnosed with ADHD. This article presents the rationale for EEG biofeedback and examines the empirical support for this treatment using efficacy guidelines established by the Association for Applied Psychophysiology and Biofeedback and the International Society for Neuronal Regulation. Based on these guidelines, EEG biofeedback is considered to be "probably efficacious" for the treatment of ADHD and merits consideration as a treatment for patients who are stimulant "nonresponders." Although research findings published to date indicate positive clinical response in approximately 75% of patients treated in controlled group studies, additional randomized, controlled trials are needed to provide a better estimate of the robustness of this treatment.

Monastra, V. J., Lynn, S., Linden, M., Lubar, J. F., Gruzelier, J., & LaVaque, T. J. (2005). Electroencephalographic biofeedback in the treatment of attention-deficit/hyperactivity disorder. *Applied Psychophysiology & Biofeedback*, 30(2), 95-114. Historically, pharmacological treatments for attention-deficit/hyperactivity disorder (ADHD) have been considered to be the only type of interventions effective for reducing the core symptoms of this condition. However, during the past three decades, a series of case and controlled group studies examining the effects of EEG biofeedback have reported improved attention and behavioral control, increased cortical activation on quantitative electroencephalographic examination, and gains on tests of intelligence and academic achievement in response to this type of treatment. This review paper critically examines the empirical evidence, applying the efficacy guidelines jointly established by the Association for Applied Psychophysiology and Biofeedback (AAPB) and the International Society for Neuronal Regulation (ISNR). On the basis of these scientific principles, EEG biofeedback was determined to be "probably efficacious" for the treatment of ADHD. Although significant clinical improvement was reported in approximately 75% of the patients in each of the published research studies, additional randomized, controlled group studies are needed in order to provide a better estimate of the percentage of patients with ADHD who will demonstrate such gains in clinical practice.

Monastra, V. J., Monastra, D. M., & George, S. (2002). The effects of stimulant therapy, EEG biofeedback, and parenting style on the primary symptoms of attention-deficit/hyperactivity disorder. *Applied Psychophysiology & Biofeedback*, 27(4), 231-249. One hundred children, ages 6-19, who were diagnosed with attention-deficit/hyperactivity disorder (ADHD), either inattentive or combined types, participated in a study examining the effects of Ritalin, EEG biofeedback, and parenting style on the primary symptoms of ADHD. All of the patients participated in a 1-year, multimodal, outpatient program that included Ritalin, parent counseling, and academic support at school (either a 504 Plan or an IEP). Fifty-one of the participants also received EEG biofeedback therapy. Post treatment assessments were conducted both with and without stimulant therapy. Significant improvement was noted on the Test of Variables of Attention (TOVA; L. M. Greenberg, 1996) and the Attention Deficit Disorders Evaluation Scale (ADDES; S. B. McCarney, 1995) when participants were tested while using Ritalin. However, only those who had received EEG biofeedback sustained these gains when tested without Ritalin. The results of a Quantitative Electroencephalographic Scanning Process (QEEG-Scan; V. J. Monastra et al., 1999) revealed significant reduction in cortical slowing only in patients who had received EEG biofeedback. Behavioral measures indicated that parenting style exerted a significant moderating effect on the expression of behavioral symptoms at home but not at school.

Mulholland, T. Goodman, D., & Boudrot, R. (1983). Attention and regulation of EEG alpha-attenuation responses. *Biofeedback & Self-Regulation,* 8(4), 585-600. Two experiments with 16 normal adults of both sexes tested the hypothesis that inattention to a biofeedback display is associated with increased variability of those physiological processes that had been regulated by the biofeedback. Each experiment was a repeated-measures-on-independent-subjects-design. Dependent variables were the time durations and the mean rms power of two mutually exclusive segments of the parietal-occipital EEG: alpha and not-alpha segments. Independent variables were combination of counting tasks and instructions to look at, listen to, and count visual and auditory flashes and clicks. The durations of alpha and not-alpha segments were controlled or

regulated by means of an alpha-contingent visual feedback stimulus; attention to the feedback stimulus was challenged by instructions to count other, noncontingent stimuli. Control of alpha and not-alpha segments was least for conditions of (1) "sham" feedback, and (2) feedback with instructions to count noncontingent auditory clicks, which were presented 3/sec while the feedback visual stimuli were occurring. A new EEG test of attention and distraction was suggested.

Nash, J. K. (2000). Treatment of attention-deficit hyperactivity disorder with neurotherapy. *Clinical Electroencephalography*, 31(1), 30-37. Significant public health concerns exist regarding our current level of success in treating ADHD. Medication management is very helpful in 60-70% of patients. Side effects, lack of compliance and the fact that stimulant medications cannot be given late in the day limit the benefits largely to school hours. While stimulants improve behavior and attention, less of an effect has been noted on academic and social performance. Continuing concerns exist about long-term safety, and studies on long-term cardiovascular and neurophysiological effects have not been carried out. Neurotherapy for ADHD offers an effective alternate for patients whose treatment is limited by side effects, poor medication response and in cases in which the patients and/or their parents refuse to consider medications. Studies indicate clinical improvement is largely related to measurable improvements in the EEG signature, evidenced by declining theta/beta ratios over frontal/central cortex and/or reduced theta/alpha band amplitudes.

Omizo, M. M., & Michael, W. B. (1982). Biofeedback-induced relaxation training and impulsivity, attention to task, and locus of control among hyperactive boys. *Journal of Learning Disabilities*:15(2). 414-416. This study examines the effects of biofeedback-induced relaxation training on impulsivity, attention to task, and locus of control among 32 hyperactive boys. Subjects, who were identified through teacher ratings on the abbreviated form of the Conners' Behavior Rating Scale, were randomly assigned to experimental (n= 16) and control (n= 16) groups. The experimental treatment consisted of four sessions of biofeedback-induced relaxation training spaced approximately two weeks apart. Multivariate analysis of variance results indicated a significant difference between groups, $F (3, 28) = 19.62$, $p<.01$. Univariate F tests and discriminant analysis procedures revealed that impulsivity and attention to task measures were significant discriminators, both $p<.01$. The locus of control variable did not prove to be a valid discriminator. It was concluded that biofeedback-induced relaxation training increased attention to task and reduced impulsivity but did not affect the measure of locus of control on the population studied.

Othmer, S., Othmer, SF., Kaiser, DA. & Putman, D. (2014). Endogenous neuromodulation at infra-slow frequencies. Semin Pediatr Neurol:20(4). Neuromodulation in the bioelectrical domain is an attractive option for the remediation of functionally-based deficits. Most of the interest to date has focused on exogenous methods such as repetitive transcranial magnetic stimulation (rTMS), transient DC Stimulation (tDCS), vagus nerve stimulation (VNS), and deep brain stimulation (DBS). Much less attention has been given to endogenous methods of exploiting latent brain plasticity. These have reached a level of sophistication and maturity that invites attention. Over the last seven years the domain of infra-low frequencies has been exploited productively for the enhancement of neuroregulation. The principal mechanism is putatively the re-normalization of functional connectivity of our resting state networks. The endogeneous techniques are particularly attractive for

the pediatric population, where they can be utilized before dysfunctional patterns of brain behavior become consolidated and further elaborated into clinical syndromes.

Perreau-Linck, E., Lessard, N., Lévesque, J., Beauregard, M. (2010). Effects of neurofeedback training on inhibitory capacities in ADHD children: A single-blind, randomized, placebo-controlled study. *Journal of Neurotherapy* 14(3), 229 - 242. Introduction: Studies performed during the last decades suggest that neurofeedback (NF) training can effectively reduce symptomatology in children with Attention-Deficit/Hyperactivity Disorder (ADHD). Yet, questions remain concerning specific effects of NF training in ADHD children since these studies did not use a randomized, placebo-controlled approach. To address this issue, such an approach was used in the present study to measure the impact of NF training on inhibitory capacities. Methods: Nine ADHD children (with no comorbidity), aged 8 to 13 years, were randomly assigned to either an experimental group (n = 5) or a placebo group (n = 4). For both groups, training protocols comprised 40 one-hour sessions (20 meetings of two sessions each). SMR/Theta training was used in the experimental group. Pre-recorded sessions of the first author's EEG activity were used in the placebo group. Pre- and post-training assessments consisted of the Conner's Parent Rating Scales (CPRS-R) and neuropsychological tests. A multiple case study strategy was applied for data analysis using a Reliable Change Index (RCI) when applicable. Results: One experimental subject was a drop-out and one placebo subject had to be discontinued due to adverse effects. The latter subject accepted to undergo post-training evaluations; hence an Intention-To-Treat analysis was performed on this subject's data. Remaining subjects showed significant improvements on the CPRS-R. Improvements were measured on the Variability measure of the CPT-II consistently across the placebo group and on the Inhibition Condition of the Stroop Task for all but one placebo subject. The same trend was found for the Inhibition/Switching Condition (Stroop Task) across the experimental group (n=4).

Ponomev, VA., Mueller, A., Candrian, G., Grin-Yatensko, VA, & Kropotov, J. (2013). Group Independent Component Analysis (gICA) and Current Source Density (CSD) in the study of EEG in ADHD adults. Clinical Neurophysiology: http://dx.doi.org/10.1016/j.clinph.2013.06.015. Objective: To investigate the performance of the spectral analysis of resting EEG, Current Source Density (CSD) and group independent components (gIC) in diagnosing ADHD adults. Methods: Power spectra of resting EEG, CSD and gIC (19 channels, linked ears reference, eyes open/closed) from 96 ADHD and 376 healthy adults were compared between eyes open and eyes closed conditions, and between groups of subjects. Results: Pattern of differences in gIC and CSD spectral power between conditions was approximately similar, whereas it was more widely spatially distributed for EEG. Size effect (Cohen's d) of differences in gIC and CSD spectral power between groups of subjects was considerably greater than in the case of EEG. Significant reduction of gIC and CSD spectral power depending on conditions was found in ADHD patients. Reducing power in a wide frequency range in the fronto-central areas is a common phenomenon regardless of whether the eyes were open or closed. Conclusions: Spectral power of local EEG activity isolated by gICA or CSD in the fronto-central areas may be a suitable marker for discrimination of ADHD and healthy adults. Significance: Spectral analysis of gIC and CSD provides better sensitivity to discriminate ADHD and healthy adults.

Pulvermuller, F., Mohr, B., Schleichert, H., & Veit, R. (2000). Operant conditioning of left-hemispheric slow cortical potentials and its effect on word processing. ***Biological Psychology,*** **53, 177-215.** This study investigated whether language-related cognitive processes can be modified by learned modulation of cortical activity. Study participants received feedback of slow cortical potentials (SCPs) recorded above left-hemispheric language cortices and were reinforced for producing negative and positive shifts upon two different discriminative stimuli. In all subjects who achieved reliable control of left-hemispheric brain responses, substantial modification of word processing was observed. Behavioral modification could be documented in two experiments in which word probes were presented following discriminative stimuli. When negative shifts of the EEG were required, lexical decisions on words were substantially speeded, while they were slowed during positivity conditions. There was no indication for any performance difference between conditions in control subjects who failed to achieve control over SCPs after feedback training. This result was replicated in an experiment using lateralized-tachistoscopic stimulus presentation. Comparisons of word and pseudoword responses in both experiments indicated that behavioral modification was most pronounced for word responses. It was also not seen in a simple reaction time task not involving language materials. This argues against a global effect related to perception, visuo-spatial attention, or motor processes. We conclude that linguistic processes can be influenced by modification of cortical activity due to operant conditioning. In closing, tentative explanations of the present results based on theories of language and attention processes are being discussed

Rasey, H. W., Lubar, J. E., McIntyre, A., Zoffuto, A. C., & Abbott, P. L. (1996). EEG biofeedback for the enhancement of attentional processing in normal college students. ***Journal of Neurotherapy*****, 1(3), 15-21.** College students diagnosed as free of any neurological or attention deficit disorder received EEG biofeedback to enhance beta (16-22 HZ) activity while simultaneously inhibiting high theta and low alpha (6-10 Hz) activity in order to evaluate improvements in attentional measurers. Following short-term treatment (mean number of sessions = 20), subjects were evaluated as either learners or non-learners based upon standard pre- and post-treatment neurofeedback measurers. Attention quotients taken from pre- and post-treatment measurements using the Integrated Visual and Auditory Continuous Performance Test (IVA) identified significant improvements in attentional measures in learners, while non-learners showed no significant improvements. Results suggest that some “normal” young adults can learn to increase EEG activity associated with improved attention. Twenty sessions, however, even for this population may represent the lower limit for achieving significant improvement.

Rockstroh, B., Elbert, T., Lutzenberger, W., & Birbaumer, N. (1990). Biofeedback: Evaluation and therapy in children with attentional dysfunction. Chapter in A. Rothenberger (Ed.), ***Brain and Behaviour in Child Psychiatry*****. Berlin: Springer Verlag, pp. 345-357.** Background: Learned self-control of slow cortical potentials (SCPs) may lead to behavioral improvement in attention-deficit/ hyperactivity disorder (ADHD). Hence, training effects should also be reflected at the neurophysiological level. Methods: Thirteen children with ADHD, aged 7-13 years, performed 25 SCP training sessions within 3 weeks. Before and after training, the German ADHD rating scale was completed by parents, and event-related potentials were recorded in a cued continuous

performance test (CPT). For a waiting-list group of nine children with ADHD, the same testing was applied. Results: ADHD symptomatology was reduced by approximately 25% after SCP training. Moreover, a decrease of impulsivity errors and an increase of the contingent negative variation were observed in the CPT task. Conclusions: This study provides first evidence for both positive behavioral and specific neurophysiological effects of SCP training in children with ADHD.

Rossiter, T. (2002). Neurofeedback for AD/HD: A ratio feedback case study. *Journal of Neurotherapy*, 6(3), 9-35. Introduction. The case study of a 13-year-old AD/HD male treated with neurofeedback is the subject matter for a tutorial on Ratio feedback. Method. Neurofeedback was conducted at C3 (increase 15 to 18 Hz, decrease 2 to 10 Hz) and C4 (increase 12 to 15 Hz, decrease 2 to 7 Hz). Protocols provided visual and auditory feedback based on the ratio of slow wave activity to be suppressed divided by fast wave activity to be enhanced (Ratio feedback). Results. The patient demonstrated marked improvement in processing speed and variability on the Test of Variables of Attention-Auditory, a 19-point increase in IQ on the Kaufman Brief Intelligence Test, significant behavioral improvement based on parental (Behavior Assessment System for Children) and patient (Brown ADD Scale) reports, and a 7.5 grade equivalent increase in reading scores (Kaufman Test of Educational Achievement-Brief Form). At the 17-month follow-up parent questionnaires indicated that the patient's behavioral gains had been maintained or were slightly improved. EEG data showed significant declines in the C4/SMR Ratio (10*2 to 7 Hz/12 to 15 Hz) and 2 to 7 Hz amplitude, a tendency toward an increase in 12 to 15 Hz amplitude, a significant increase in 8 to 11 Hz amplitude, and a decline in 22 to 30 Hz amplitude. Beta activity (15 to 18 Hz) was unchanged. An unexpected finding was that C3/Beta (10*2 to 10 Hz/15 to 18 Hz) and C4/SMR protocols had similar effects on the EEG even though they targeted different bands to enhance and suppress. It appears that suppression of slow wave activity (2 to 7 Hz) may be the active component in both Ratio protocols and that fast wave enhancement either plays a minor (12 to 15 Hz) or no role (15 to 18 Hz). Discussion. The findings cast doubt on the assumption that the C3/Beta and C4/SMR protocols have unique effects on EEG activity. Nevertheless, they may have differential effects on brain functions related to the training sites employed. It would be useful to analyze EEG changes in successfully treated individual AD/HD patients as a first step toward understanding the effects of various treatment protocols. What the protocols are intended to do, and the actual effects on the EEG may be different. If there are active components common to the various AD/HD treatment protocols reported in the literature, this is one way of beginning to recognize them. Brain maps collected before, during, and at the conclusion of treatment would enhance our understanding of treatment effects of various neurofeedback protocols, lead to more focused and productive research, and ultimately facilitate the development of more efficient treatment paradigms.

Rossiter, T. R., & La Vaque, T. J. (1995). A comparison of EEG biofeedback and psychostimulants in treating attention deficit/hyperactivity disorders. *Journal of Neurotherapy*, 1, 48-59. The study compared the effects of EEG biofeedback and stimulant medication in reducing AD/HD symptoms. Stimulants are the most widely used treatment for AD/HD but have drawbacks. The most serious is that symptom reduction is only temporary unless medication is taken indefinitely. In addition, stimulants may have side effects and long-term compliance with taking the medication is poor, especially among adolescents. The study compared treatment

programs with 20 sessions of EEG biofeedback (n = 23) or stimulants (n = 23) as their primary components. An EEG group (EEG) was matched with a stimulant group (MED) by age, IQ, gender, and diagnosis. The Test of Variables of Attention (TOVA) was administered pre and post-treatment. Both the EEG and MED groups improved ($p < .05$) on TOVA measures of inattention, impulsivity, information processing, and variability but did not differ from each other ($p > 0.3$) on TOVA change scores. The results indicate that the EEG biofeedback program is an effective alternative to stimulants and may be the treatment of choice when medication is ineffective, has side effects, or compliance is a problem. Previous studies suggest that EEG biofeedback leads to lasting symptom reduction. This needs to be confirmed with larger samples using standardized assessment procedures.

Sherlin, L., Arns, M., Lubar, J., & Sokhadze, E. (2010). A position paper on neurofeedback for the treatment of ADHD. *Journal of Neurotherapy*, 14, 66-78. This position paper provides the current evidence supporting the use of neurofeedback in the treatment of ADHD and recommendations on the implementation of neurofeedback in clinical practice. The paper also provides basic information regarding the diagnosis and psychophysiological etiology of ADHD. The paper does not focus on a specific age range of a clinical population. Unless otherwise noted, we are referring to all subtypes of ADHD (inattentive, hyperactive only, and combined). Conclusions and recommendation are based on the most recent research; however, we also refer to relevant historical studies that support our position on neurofeedback. The readers are strongly advised to research behavioral diagnostic criteria and testing methods elsewhere. This paper is not intended as a comprehensive educational tool for diagnosis or treatment of ADHD. Our purpose is to demonstrate the rationale and to reference the necessary support for neurofeedback in order to be recognized as a legitimate, scientific, and evidence-based intervention for the treatment of ADHD.

Simkin, DR., Thatcher, RW. & Lubar, J. (2014). Quantitative EEGB and Neurofeedback in Children and adolescents: Anxiety disorders, depressive disorders, comorbid addiction and attention-deficit/hyperactivity disorder and brain injury. *Child and Adolescent Psychiatric Clinics of North America*:23(3). 427-464. This article explores the science surrounding neurofeedback. Both surface neurofeedback (using 2-4 electrodes) and newer interventions, such as real-time z-score neurofeedback (electroencephalogram [EEG] biofeedback) and low-resolution electromagnetic tomography neurofeedback, are reviewed. The limited literature on neurofeedback research in children and adolescents is discussed regarding treatment of anxiety, mood, addiction (with comorbid attention-deficit/hyperactivity disorder), and traumatic brain injury. Future potential applications, the use of quantitative EEG for determining which patients will be responsive to medications, the role of randomized controlled studies in neurofeedback research, and sensible clinical guidelines are considered.

Shin, D. I., Lee, J. H., Lee, S. M., Kim, I. Y., & Kim, S. I. (2004). Neurofeedback training with virtual reality for inattention and impulsiveness. *Cyberpsychology & Behavior*, 7(5), 519-526. In this research, the effectiveness of neurofeedback, along with virtual reality (VR), in reducing the level of inattention and impulsiveness was investigated. Twenty-eight male participants, aged 14-18, with social problems, took part in this study. They were separated into three groups: a control group, a VR group, and a non-VR group. The

VR and non-VR groups underwent eight sessions of neurofeedback training over 2 weeks, while the control group just waited during the same period. The VR group used a head-mounted display (HMD) and a head tracker, which let them look around the virtual world. Conversely, the non-VR group used only a computer monitor with a fixed viewpoint. All participants performed a continuous performance task (CPT) before and after the complete training session. The results showed that both the VR and non-VR groups achieved better scores in the CPT after the training session, while the control group showed no significant difference. Compared with the other groups, the VR group presented a tendency to get better results, suggesting that immersive VR is applicable to neurofeedback for the rehabilitation of inattention and impulsiveness.

Shouse, M. N., & Lubar, J. F. (1979). Operant conditioning of EEG rhythms and Ritalin in the treatment of hyperkinesis. *Biofeedback & Self-Regulation*, 4(4), 299-311. Enhanced voluntary motor inhibition regularly accompanies conditioned increases in the sensorimotor rhythm (SMR), a 12–14-Hz Rolandic EEG rhythm in cats. A similar rhythm, presumably SMR, has also been identified in the human EEG. The clinical effectiveness of SMR operant conditioning has been claimed for epilepsy, insomnia, and hyperkinesis concurrent with seizure disorders. The present report attempts to follow up and replicate preliminary findings that suggested the technique's successful application to hyperkinesis uncomplicated by a history of epilepsy. SMR was defined as 12--14-Hz EEG activity in the absence of high-voltage slow-wave activity between 4 and 7 Hz. Anticipated treatment effects were indexed by systematic behavioral assessments of undirected motor activity and short attention span in the classroom. EEG and behavioral indices were monitored in four hyperkinetic children under the following six conditions: (1) No Drug, (2) Drug Only, (3) Drug and SMR Training I, (4) Drug and SMR Reversal Training, (5) Drug and SMR Training II, (6) No Drug and SMR Training. All hyperkinetic subjects were maintained on a constant drug regimen throughout the phases employing chemotherapy. Contingent increases and decreases in SMR occurred in three of four training subjects and were associated with similar changes in classroom assessments of motor inactivity. Combining medication and SMR training resulted in substantial improvements that exceeded the effects of drugs alone and were sustained with SMR training after medication was withdrawn. In contrast, these physiological and behavioral changes were absent in one highly distractible subject who failed to acquire the SMR task. Finally, pretraining levels of SMR accurately reflected both the seve-ity of original motor deficits and the susceptibility of hyperkinetic subjects to both treatments. Although the procedure clearly reduced hyperkinetic behavior, a salient, specific therapeutic factor could not be identified due to the dual EEG contingency imposed combined with associated changes in EMG. Despite these and other qualifying factors, the findings suggested the prognostic and diagnostic value of the SMR in the disorder when overactivity rather than distractibility is the predominant behavioral deficit.

Steiner, NJ., Frenette, EC., Rene, KM., Brennan, RT & Perrin, EC. (2014). In-school neurofeedback training for ADHD: Sustained improvements from a randomized control trial. Pediatrics:133. 483. OBJECTIVE: To evaluate sustained improvements 6 months after a 40-session, in-school computer attention training intervention using neurofeedback or cognitive training (CT) administered to 7- to 11-year-olds with attention-deficit/hyperactivity disorder (ADHD). METHODS: One hundred four children were randomly assigned to receive neurofeedback, CT, or a control condition and were evaluated 6 months postintervention. A 3-point growth

model assessed change over time across the conditions on the Conners 3-Parent Assessment Report (Conners 3-P), the Behavior Rating Inventory of Executive Function Parent Form (BRIEF), and a systematic double-blinded classroom observation (Behavioral Observation of Students in Schools). Analysis of variance assessed community-initiated changes in stimulant medication. RESULTS: Parent response rates were 90% at the 6-month follow-up. Six months postintervention, neurofeedback participants maintained significant gains on Conners 3-P (Inattention effect size [ES] = 0.34, Executive Functioning ES = 0.25, Hyperactivity/Impulsivity ES = 0.23) and BRIEF subscales including the Global Executive Composite (ES = 0.31), which remained significantly greater than gains found among children in CT and control conditions. Children in the CT condition showed delayed improvement over immediate postintervention ratings only on Conners 3- P Executive Functioning (ES = 0.18) and 2 BRIEF subscales. At the 6- month follow-up, neurofeedback participants maintained the same stimulant medication dosage, whereas participants in both CT and control conditions showed statistically and clinically significant increases (9 mg [P = .002] and 13 mg [P , .001], respectively). CONCLUSIONS: Neurofeedback participants made more prompt and greater improvements in ADHD symptoms, which were sustained at the 6-month follow-up, than did CT participants or those in the control group. This finding suggests that neurofeedback is a promising attention training treatment for children with ADHD. Pediatrics 2014;133:483- 492

Steiner, NJ., Frenette, EC., Rene, KM., Brennan, RT & Perrin, EC. (2014). Neurofeedback and cognitive attention training for children with attention-deficit hyperactivity disorder in schools. J Dev Bahav Peadiatr:35(1). 18-27. OBJECTIVE: To evaluate the efficacy of 2 computer attention training systems administered in school for children with attention-deficit hyperactivity disorder (ADHD). METHOD: Children in second and fourth grade with a diagnosis of ADHD (n = 104) were randomly assigned to neurofeedback (NF) (n = 34), cognitive training (CT) (n = 34), or control (n = 36) conditions. A 2-point growth model assessed change from pre-post intervention on parent reports (Conners 3-Parent [Conners 3-P]; Behavior Rating Inventory of Executive Function [BRIEF] rating scale), teacher reports (Swanson, Kotkin, Agler, M-Flynn and Pelham scale [SKAMP]; Conners 3-Teacher [Conners 3-T]), and systematic classroom observations (Behavioral Observation of Students in Schools [BOSS]). Paired t tests and an analysis of covariance assessed change in medication. RESULTS: Children who received NF showed significant improvement compared with those in the control condition on the Conners 3-P Attention, Executive Functioning and Global Index, on all BRIEF summary indices, and on BOSS motor/verbal off-task behavior. Children who received CT showed no improvement compared to the control condition. Children in the NF condition showed significant improvements compared to those in the CT condition on Conners 3-P Executive Functioning, all BRIEF summary indices, SKAMP Attention, and Conners 3-T Inattention subscales. Stimulant medication dosage in methylphenidate equivalencies significantly increased for children in the CT (8.54 mg) and control (7.05 mg) conditions but not for those in the NF condition (0.29 mg). CONCLUSION: Neurofeedback made greater improvements in ADHD symptoms compared to both the control and CT conditions. Thus, NF is a promising attention training treatment intervention for children with ADHD.

Strehl, U., Leins, U., Goth, G., Klinger, C., Hinterberger, T., and Birbaumer, N. (2006). Self-regulation of slow cortical potentials: A new treatment for children with attention deficit/hyperactivity disorder. *Pediatrics*, 118, 1530-1540. We investigated the effects of self-regulation of slow cortical potentials for children with attention-deficit/hyperactivity disorder. Slow cortical potentials are slow event-related direct-current shifts of the electroencephalogram. Slow cortical potential shifts in the electrical negative direction reflect the depolarization of large cortical cell assemblies, reducing their excitation threshold. This training aims at regulation of cortical excitation thresholds considered to be impaired in children with attention-deficit/hyperactivity disorder. Electroencephalographic data from the training and the 6-month follow-up are reported, as are changes in behavior and cognition. Twenty-three children with attention-deficit/hyperactivity disorder aged between 8 and 13 years received 30 sessions of self-regulation training of slow cortical potentials in 3 phases of 10 sessions each. Increasing and decreasing slow cortical potentials at central brain regions was fed back visually and auditorily. Transfer trials without feedback were intermixed with feedback trials to allow generalization to everyday-life situations. In addition to the neurofeedback sessions, children exercised during the third training phase to apply the self-regulation strategy while doing their homework. For the first time, electroencephalographic data during the course of slow cortical potential neurofeedback are reported. Measurement before and after the trials showed that children with attention-deficit/hyperactivity disorder learn to regulate negative slow cortical potentials. After training, significant improvement in behavior, attention, and IQ score was observed. The behavior ratings included Diagnostic and Statistical Manual of Mental Disorders criteria, number of problems, and social behavior at school and were conducted by parents and teachers. The cognitive variables were assessed with the Wechsler Intelligence Scale for Children and with a computerized test battery that measures several components of attention. All changes proved to be stable at 6 months' follow-up after the end of training. Clinical outcome was predicted by the ability to produce negative potential shifts in transfer sessions without feedback.

Studer, P., Kratz, O., Gevensleben, H., Rothenberger, A., Moll, GH., Hautzinger, M & Heinrich, H. (2014). Frontiers in Human Neuroscience:24(8) 555. Neurofeedback (NF) is being successfully applied, among others, in children with attention deficit/hyperactivity disorder (ADHD) and as a peak performance training in healthy subjects. However, the neuronal mechanisms mediating a successful NF training have not yet been sufficiently uncovered for both theta/beta (T/B), and slow cortical potential (SCP) training, two protocols established in NF in ADHD. In the present, randomized, controlled investigation in adults without a clinical diagnosis (n = 59), the specificity of the effects of these two NF protocols on attentional processes and motor system excitability were to be examined, focusing on the underlying neuronal mechanisms. Neurofeedback training consisted of 10 double sessions, and self-regulation skills were analyzed. Pre- and post-training assessments encompassed performance and event-related potential measures during an attention task, and motor system excitability assessed by transcranial magnetic stimulation. Some NF protocol-specific effects have been obtained. However, due to the limited sample size medium effects did not reach the level of significance. Self-regulation abilities during negativity trials of the SCP training were associated with increased contingent negative variation amplitudes, indicating improved resource allocation during cognitive preparation. Theta/beta training was associated with increased response speed and decreased target-P3 amplitudes after successful theta/beta regulation suggested reduced attentional resources necessary for stimulus evaluation. Motor system excitability

effects after theta/beta training paralleled the effects of methylphenidate. Overall, our results are limited by the non-sufficiently acquired self-regulation skills, but some specific effects between good and poor learners could be described. Future studies with larger sample sizes and sufficient acquisition of self-regulation skills are needed to further evaluate the protocol-specific effects on attention and motor system excitability reported.

Swingle, P. G. (2001). Parameters associated with rapid neurotherapeutic treatment of common ADD (CADD). ***Journal of Neurotherapy*****, 5(4), 73-84.** Paralysis after stroke or neurotrauma is among the leading causes of long-term disability in adults. The development of brain-computer-interface (BCI) systems that allow online classification of electric or metabolic brain activity and their translation into control signals of external devices or computers have led to two major approaches in tackling the problem of paralysis. While assistive BCI systems strive for continuous high-dimensional control of robotic devices or functional electric stimulation (FES) of paralyzed muscles to substitute for lost motor functions in a daily life environment (e.g. Velliste et al. 2008 [1], Hochberg et al. 2006 [2], Pfurtscheller et al. 2000 [3]), restorative BCI systems aim at normalization of neurophysiologic activity that might facilitate motor recovery (e.g. Birbaumer et al. 2007, 2009 [4,5]; Daly et al. 2008 [6]). In order to make assistive BCI systems work in daily life, high BCI communication speed is necessary, an issue that by now can only be achieved by invasive recordings of brain activity (e.g. via multi-unit arrays, MUA, or electrocorticogramm, ECoG). Restorative BCI systems, in contrast, were developed as training tools based on non-invasive methods such as electro- or magnetoencephalography (EEG / MEG). More recently developed approaches use real-time functional magnetic resonance imaging (rtfMRI) or near-infrared spectroscopy (NIRS). Here, we provide an overview of the current state in the development and application of assistive and restorative BCI and introduce novel approaches to improve BCI control with brain stimulation such as transcranial direct current stimulation (tDCS). The outlook of using BCI in rehabilitation of stroke and neurotrauma is discussed.

Tansey, M. A. (1984). EEG sensorimotor rhythm biofeedback training: Some effects on the neurological precursors of learning disabilities. ***International Journal of Psychophysiology*****, 3, 85-99.** This study presents a clinical treatment regime for pathological interhemispheric dysfunction with respect to a population of learning disabled boys. The results obtained replicate and extend earlier findings with respect to operantly conditioned increases in amplitude of sensorimotor transactions and its positive effect on learning disability. Specifically, the biofeedback, and subsequent conditioning, of increased 14 Hz neural discharge patterns (sensorimotor rhythm-SMR) over the central Rolandic cortex, appeared to increase bilateral sensorimotor transactions resulting in substantive reduction/remediation in the learning disabilities of the recipients of such EEG biofeedback training.

Tansey, M. A. (1985). Brainwave signatures--An index reflective of the brain=s functional neuroanatomy: Further findings on the effect of EEG sensorimotor rhythm biofeedback training on the neurologic precursors of learning disabilities. ***International Journal of Psychophysiology*****, 3, 85-89.** Eight boys, ages 7 years 11 months to 15 years 3 months, were provided with long-term--symptom duration--sensorimotor rhythm biofeedback training for the remediation of their learning disabilities. Concurrently, the simultaneous recording of five frequency bands of brainwave activity (5 Hz, 7 Hz, 10 Hz, 12 Hz and 14 Hz), from one active

electrode equidistant from reference and ground, was intended to provide a glimpse of the 'brainwave signature' reflective of the dynamic and synergistic processes involved in such cerebro-neural activation and the brain's global response to such an alteration in the sensorimotor subnetwork. Overall, the main effect of this procedure, for the biofeedback and subsequent conditioning of increased 14 Hz neural discharge patterns over the central Rolandic cortex in a clinical office setting, seems to be to increase bilateral sensorimotor transactions resulting in substantive remediation of the learning disabilities of the recipients of such training--by way of internally exercising of, and/or recruitment of additional neural activation within, the sensorimotor subnetwork/matrix. Observation of the changing brainwave signatures showed a tendency for decreased slow wave activity concomitant with increases in fast wave activity, for cases with a Full Scale I.Q. within the range of 76 and 85; with those cases with a Full Scale I.Q. within the range of 102 and 116 exhibiting increased amplitudes over most of the monitored bands, but with the increases being much less at the slower frequencies. It is noteworthy that those four subjects with either a significant Verbal greater than Performance, or Performance greater than Verbal, I.Q. Score discrepancy exhibited no less than a 40% greater increase in the lower of the two I.Q. scores; indicating that this SMR training procedure also resulted in an increased symmetry in the interhemispheric interactions reflective of the higher cortical functions for these no longer learning disabled boys.

Tansey, M. A. (1993). Ten-year stability of EEG biofeedback results for a hyperactive boy who failed fourth grade perceptually impaired class. *Biofeedback & Self-Regulation*, 18, 33-44. Ten years ago, the first successful application of a clinical, private-practice based, EEG 14-Hz biofeedback training regimen for the treatment of learning disorders was performed by the author. After the 10-year-old boy, with presenting symptomatology including a developmental reading disorder, hyperactivity, and an educational classification of perceptually impaired, continued symptom free for a period of two years, his case was submitted for publication. Ten years after his termination from successful treatment, his ongoingly normal social and academic functioning is noted and his EEG brainwave signature examined and compared with a population of 24 "used-to-be" learning disabled, one-half of which had a pretreatment state including the educational classification of perceptually impaired. This 10-year follow-up confirms the long-term stability of the results of this EEG 14-Hz biofeedback regimen. Current findings on recent medical research identifying a major cerebral locus of dysfunction for hyperkinesis and how it supports the electrode placements of this clinical office setting regimen is also discussed.

Tansey, M. A., & Bruner, R. L. (1983). EMG and EEG biofeedback training in the treatment of 10-year old hyperactive boy with a developmental reading disorder. *Biofeedback & Self-Regulation*, 8(1), 25-37. The serial application of electromyographic (EMG) and sensorimotor (SMR) biofeedback training was attempted with a 10-year-old boy presenting a triad of symptoms: an attention deficit disorder with hyperactivity, developmental reading disorder, and ocular instability. Symptom elimination was achieved, for all three aspects of the triad, following the procedure of first conditioning a decrease in EMG-monitored muscle tension and then conditioning increases in the amplitude of sensorimotor rhythm over the Rolandic cortex. The learned reduction of monitored EMG levels was accompanied by a reduction in the child's motoric activity level to below that which had been achieved by past administration of Ritalin. In addition, the attention deficit disorder

with hyperactivity was no longer diagnosable following the EMG biofeedback training. The learned increase in the amplitude of monitored SMR was accompanied by remediation of the developmental reading disorder and the ocular instability. These results remained unchanged, as ascertained by follow-ups conducted over a 24-month period subsequent to the termination of biofeedback training.

Thompson, L., & Thompson, M. (1998). Neurofeedback combined with training in metacognitive strategies: Effectiveness in students with ADD. *Applied Psychophysiology & Biofeedback*, 23(4), 243-263. Seven autistic children diagnosed with autism spectrum disorders (ASD) received a neurofeedback treatment that aimed to improve their level of executive control. Neurofeedback successfully reduced children's heightened theta/beta ration by inhibiting theta activation and enhancing beta activation over sessions. Following treatment children's executive capacities were found to have improved greatly relative to pre-treatment assessment on a range of executive function tasks. Additional improvements were found in children's social, communicative and typical behavior, relative to a waiting list control group. These findings suggest a basic executive function impairment in ASD that can be alleviated through specific neurofeedback treatment. Possible neural mechanisms that may underlie neurofeedback mediated improvement in executive functioning in autistic children are discussed.

Williams, J. (2010). Does neurofeedback help reduce attention-deficit hyperactivity disorder? *Journal of Neurotherapy*, 14(4), 261-279. Introduction: Neurofeedback is an alternative treatment for Attention Deficit Hyperactivity Disorder (ADHD), but its efficacy is unknown. This narrative review examines rigorous studies conducted utilizing neurofeedback as a treatment for ADHD. Methods: Studies were located by searching the Web of Science and PsycINFO databases with the keywords ADHD or attention deficit hyperactivity disorder AND neurofeedback or EEG biofeedback or electroencephalogram biofeedback. Located studies were chosen for initial review if they met the following criteria: (a) randomized controlled trial or quasi-experiment, (b) ADHD diagnosis based on DSM criteria, (c) published at any time prior to March 2010, (d) English language, and (e) published in a peer-reviewed journal. Participants included children, adolescents, and adults diagnosed with ADHD. Results: Twelve articles reporting 9 different studies met the eligibility criteria and were included in the review. All 9 studies produced results that indicated significant improvements on either tests scores or behavioral conduct for individuals who were treated with neurofeedback for ADHD. Alternative treatments also demonstrated effectiveness. Conclusion: Neurofeedback may be an effective treatment for ADHD. Future research is needed with larger sample sizes, comparing the efficacy of neurofeedback with the efficacy of other ADHD treatments and comparing different neurofeedback protocols.

Vachon-Presseau, E., Achim, A., Benoit-Lajoie, A. (2009). Direction of SMR and beta change with attention in adults. *Journal of Neurotherapy* 13(1), 22 - 29. Introduction. The aim of this study was to clarify the interpretation of sensory-motor rhythm (SMR; 13–15 Hz) and beta (16–20 Hz) changes with respect to attention states. Method. For this purpose, EEG was recorded from 11 participants during (a) a multiple object tracking task (MOT), which required externally directed attention; (b) the retention phase of a visuo-spatial memory task (VSM), which required internally directed attention and avoidance of sensory distraction; and (c) the waiting intervals between trials, which constituted a no-task-imposed control condition. The 2 active tasks were

consecutively presented at 2 difficulty levels (i.e., easy and hard). Two analyses of variance were conducted on EEG log spectral amplitudes in the alpha (8-12 Hz), SMR, and beta bands from F3, F4, C3, C4 and P3, P4. Results. The first 15 analysis compared the MOT to the VSM by difficulty levels and revealed a significant task effect ($p < .0005$) but no effect of difficulty. The results showed that externally directed attention (MOT) resulted in lower values than internally directed attention (VSM) in all three bands. The second analysis averaged the difficulty levels together and added the no-task-imposed reference condition. The results again showed a significant task effect that did not interact with site, hemisphere, or, more important, band. Post hoc tests revealed that both MOT and VSM produced significantly smaller means than the no-task-imposed condition. This pattern of log-amplitude means and the lack of task interaction with any other factor indicate that task-induced attention reduces EEG power in the same proportion across the 3 bands and the 6 channels studied. Conclusions. These results contradict a frequent interpretation concerning the relationship between the brain's aptitude to increase low beta in neurofeedback programs and improved sustain attention capacities.

Valdez, M. (1985). Effects of biofeedback-assisted attention training in a college population. *Biofeedback & Self-Regulation*, 10(4), 315-324. A program of stress management employing open-focus attention-training workshops was developed at Baruch College to bring the benefits of stress reduction to students. The purpose of the research reported here was to evaluate the results of the open-focus attention-training technique. Open-focus technique without biofeedback training was used for two semesters. Biofeedback training was incorporated in the third semester. In the first study, changes in grade point average (GPA), stress-related symptoms, and physiological measures were examined. The experimental subjects' stress data for this study was reported previously (Valdés, 1985). In the second study, changes in the same variables for experimental and control subjects were evaluated. Students in the control group showed decreased GPA, while those who participated in open-focus training showed a trend toward improved GPA. Stress-related symptoms associated with anxiety and management of emotional problems showed significant posttraining improvement, as did physiological measures in all of the biofeedback modalities in which the experimental subjects were specifically trained. The results support the hypothesis that the workshops were successful in reducing stress levels, and suggest that further controlled research be conducted to verify these findings, and to identify the most effective components of the training procedure.

Vernon, D., Egner, T., Cooper, N., Compton, T., Neilands, C., Sheri, A., & Gruzelier, J. (2003). The effect of training distinct neurofeedback protocols on aspects of cognitive performance. *International Journal of Psychophysiology*, 47, 75-85. The use of neurofeedback as an operant conditioning paradigm has disclosed that participants are able to gain some control over particular aspects of their electroencephalogram (EEG). Based on the association between theta activity (4-7 Hz) and working memory performance, and sensorimotor rhythm (SMR) activity (12-15 Hz) and attentional processing, we investigated the possibility that training healthy individuals to enhance either of these frequencies would specifically influence a particular aspect of cognitive performance, relative to a non-neurofeedback control-group. The results revealed that after eight sessions of neurofeedback the SMR-group were able to selectively enhance their SMR activity, as indexed by increased SMR/theta and SMR/beta ratios. In contrast, those trained to selectively enhance theta activity failed

to exhibit any changes in their EEG. Furthermore, the SMR-group exhibited a significant and clear improvement in cued recall performance, using a semantic working memory task, and to a lesser extent showed improved accuracy of focused attentional processing using a 2-sequence continuous performance task. This suggests that normal healthy individuals can learn to increase a specific component of their EEG activity, and that such enhanced activity may facilitate semantic processing in a working memory task and to a lesser extent focused attention. We discuss possible mechanisms that could mediate such effects and indicate a number of directions for future research.

Vollenbregt, MA., van Dongen-Boomsma, M., Slaats-Willemse, D. & Buitelaar, JK. (2014). What future research should bring to help resolving the debate about the efficacy of EEG-neurofeedback in children with ADHD. Frontiers in Human Neuroscience:15(8). 321. In recent years a rising amount of randomized controlled trials, reviews, and meta-analyses relating to the efficacy of electroencephalographic-neurofeedback (EEG-NF) in children with attention-deficit/hyperactivity disorder (ADHD) have been published. Although clinical reports and open treatment studies suggest EEG-NF to be effective, double blind placebo-controlled studies as well as a rigorous meta-analysis failed to find support for the efficacy of EEG-NF. Since absence of evidence does not equate with evidence of absence, we will outline how future research might overcome the present methodological limitations. To provide conclusive evidence for the presence or absence of the efficacy of EEG-NF in the treatment of ADHD, there is a need to set up a well-designed study that ensures optimal implementation and embedding of the training, and possibly incorporates different forms of neurofeedback.

Wadhwani, S., Radvanski, D. C., & Carmody, D. P. (1998). Neurofeedback training in a case of attention deficit hyperactivity disorder. *Journal of Neurotherapy*, 3(1), 42-49. Electroencephalographic biofeedback, also known as neurofeedback, has been used to improve attention in children with Attention Deficit Hyperactivity Disorder (ADHD). In the present case study, a ten-year-old boy completed 37 sessions of neurofeedback training over a six-month period on-site in a school setting. Beta brainwave training was applied for sessions 1 - 22 and replaced by sensorimotor rhythm training for sessions 23 - 37. A review of his national achievement test scores for four years revealed he improved performance the year he received neurofeedback and the gain was lost the year after treatment was completed. The participant had been receiving methylphenidate for the previous two years and remained on the medication throughout neurofeedback and for the year after neurofeedback treatment. Findings are suggestive of the advantages of incorporating neurofeedback training as part of a multimodal treatment program in a school setting for children with ADHD.

Walker, J. E., & Norman, C. A. (2006). The neurophysiology of dyslexia: A selective review with implications for neurofeedback remediation and results of treatment in twelve consecutive patients. *Journal of Neurotherapy*, 10(1), 45-55. Dyslexia is a common and important problem in all industrial societies, with a prevalence rate of five to ten percent, for which no consistently effective treatment is available. Recent advances in imaging (morphometric MRI, functional MRI, PET, regional cerebral blood flow), as well as in neurophysiology (evoked potentials, QEEG, event-related desynchronization, coherence studies, magnetic source imaging, reading difference topography) have clarified our understanding of the normal circuitry involved in reading and differences seen in individuals who have trouble learning to read. These studies have important

implications for the use of neurofeedback to help dyslexic individuals learn to read more easily. First, we obtain a QEEG and a reading difference topograph. We then train down any abnormalities that are significantly increased and train up any abnormalities that are significantly decreased. Increasing 16-18 Hz activity at T3 (left mid-temporal area) has also proved quite helpful in improving reading speed and comprehension. These combined approaches have been helpful in all cases of dyslexia we have treated, dramatically so in some cases. Each of the 12 individuals treated improved by at least two grade levels after 30 to 35 sessions.

Xiong, Z., Shi, S., & Xu, H. (2005). A controlled study of the effectiveness of EEG biofeedback training on children with attention deficit hyperactivity disorder. ***Journal of Huazhong University of Science & Technology*****, 25(3), 368-370.** In order to study the treatment of the children with attention deficit hyperactivity disorder (ADHD), the integrated visual and auditory continuous performance test (IVA-CPT) was clinically applied to evaluate the effectiveness of electroencephalogram (EEG) biofeedback training. Of all the 60 children with ADHD aged more than 6 years, the effective rate of EEG biofeedback training was 91.6% after 40 sessions of EEG biofeedback training. Before and after treatment by EEG biofeedback training, the overall indexes of IVA were significantly improved among predominately inattentive, hyperactive, and combined subtype of children with ADHD ($P<0.001$). It was suggested that EEG biofeedback training was an effective and vital treatment on children with ADHD.

ANXIETY, PTSD, OCD AND PANIC DISORDERS

Bazanova, OM., Balioz, NV., Muravleva, KB. & Skoraia, MV. (2013). Voluntary alpha-power increasing training impact on the heart rate variability. Fiziol Cheloveka: Jan-Feb; 39(1). 103-116. In order to study the effect of the alpha EEG power increasing training at heart rate variability (HRV) as the index of the autonomic regulation of cognitive functions there were follow tasks: (1) to figure out the impact of biofeedback in the voluntary increasing the power in the individual high-frequency alpha-band effect on heart rate variability and related characteristics of cognitive and emotional spheres, (2) to determine the nature of the relationship between alpha activity indices and heart rate variability, depending on the alpha-frequency EEG pattern at rest (3) to examine how the individual alpha frequency EEG pattern is reflected in changes HRV as a result of biofeedback training. Psychometric indicators of cognitive performance, the characteristics of the alpha-EEG activity and heart rate variability (HRV) as LF/HF and pNN50 were recorded in 27 healthy men aged 18-34 years, before, during, and after 10 sessions of training of voluntary increase in alpha power in the individual high-frequency alpha band with eyes closed. To determine the biofeedback effect on the alpha power increasing training, data subjects are compared in 2 groups: experimental (14) with the real and the control group (13 people)--with mock biofeedback. The follow up effect of trainings was studied through month over the 10 training sessions. Results showed that alpha biofeedback training enhanced the fluency and accuracy in cognitive performance, decreased anxiety and frontal EMG, increased resting frequency, width and power in individual upper alpha range only in participants with low baseline alpha frequency. While mock biofeedback increased resting alpha power only in participants with high baseline resting alpha frequency and did change neither cognitive performance, nor HRV indices. Biofeedback training eliminated the alpha power decrease in response to arithmetic task in both with high and low alpha frequency participants and this effect was followed up over the month. Mock biofeedback training has no such effect. The positive correlation between the alpha-peak frequency and pNN50 in patients with initially low, but negative--those with high baseline alpha frequency explains the multidirectional biofeedback effects on HRV in low and high alpha frequency subjects. The individual alpha-frequency EEG pattern determines the effectiveness of the alpha EEG biofeedback training in changing heart rate variability, which provides a basis for predicting the results and develop individual approaches to the biofeedback technology implementation that can be used in clinical practice for treatment and rehabilitation of psychosomatic syndromes and in educational training.

Brody, S., Rau, H., Kohler, F., Schupp, H., Lutzenberger, W., & Birbaumer, N. (1994). Slow cortical potential biofeedback and the startle reflex. *Biofeedback & Self-Regulation*, 19(1), 1-12. The negativity of slow cortical potentials (SCP) of the surface EEG is a measure of brain excitability, correlating with motor and cognitive preparation. Self-control of SCP positivity has been shown to reduce seizure activity. Following SCP biofeedback from a central EEG electrode position, subjects gained bidirectional control over their SCP. The current study used a modified feedback methodology, and found a positive relationship between negativity and magnitude of EMG startle response (a measure of cortical and subcortical arousal, particularly aversive response disposition). Greater success in SCP differentiation was associated with self-report of less relaxation during negativity training.

Chisholm, R. C., DeGood, D. E., & Hartz, M. A. (1977). Effects of alpha feedback training on occipital EEG, heart rate, and experiential reactivity to a laboratory stressor. *Psychophysiology*, 14(2), 157-163. The intent of this study was to examine whether brief alpha biofeedback training would alter the degree of physiological and experiential stress evidenced in an aversive laboratory situation. While occipital alpha and heart rate were monitored, 36 subjects underwent 8 presentations of a warning tone preceding fingertip electric shock by 30 sec. Subjects were then placed into one of three treatments taking place in dim light with eyes open. Group 1 received 24 min of contingent feedback. Group 2 received an equivalent amount of non-contingent feedback and Group 3, a no-feedback control condition, listened to music. Following the treatment period, 12 additional tone-shock pairings were presented, equally divided between eyes-open and eyes-closed trials, also with and without continuation of the treatment period "signal" (i.e. contingent, non-contingent feedback, or music). The results revealed that, in general, enhanced alpha density was maintained by the contingent feedback group during the post-treatment aversive situation. However, the reduction in alpha suppression was not systematically accompanied by corresponding heart rate and self-report reductions in situational reactivity. It was concluded that alpha feedback training was not sufficient to produce a generalized relaxation to the aversive situation. Alternative accounts of the results, focusing primarily on independence of response systems, are discussed.

Clemans, Z., El-Baz, A., Hollifield, M., & Sokhadze, E. (2012). Single trial time-frequency analysis of error processing in PTSD. *Neuroscience Letters*. E-publication. Error processing studies in psychology and psychiatry are relatively common. Event-related potentials (ERPs) are often used as measures of error processing, two such

response-locked ERPs being the error-related negativity (ERN) and the error-related positivity (Pe). The ERN and Pe occur following committed error in reaction time tasks as low frequency (4-8 Hz) electroencephalographic (EEG) oscillations registered at the midline fronto-central sites. We created an alternative method for analyzing error processing using time-frequency analysis in the form of a wavelet transform. A study was conducted in which subjects with PTSD and healthy control completed a forced-choice task. Single trial EEG data from errors in the task were processed using a continuous wavelet transform. Coefficients from the transform that corresponded to the theta range were averaged to isolate a theta waveform in the time-frequency domain. Measures called the time-frequency ERN and Pe were obtained from these waveforms for five different channels and then averaged to obtain a single time-frequency ERN and Pe for each error trial. A comparison of the amplitude and latency for the time-frequency ERN and Pe between the PTSD and control group was performed. A significant group effect was found on the amplitude of both measures. These results indicate that the developed single trial time-frequency error analysis method is suitable for examining error processing in PTSD and possibly other psychiatric disorders.

Cohen DJ, Begley A, Alman JJ, Cashmere DJ, Pietrone RN, Seres RJ, Germain A. (2013). Quantitative electroencephalography during rapid eye movement (REM) and non-REM sleep in combat-exposed veterans with and without post-traumatic stress disorder. J Sleep Res. 2013 Feb;22(1):76-82. doi: 10.1111/j.1365-2869.2012.01040.x. Epub 2012 Jul 30. Sleep disturbances are a hallmark feature of post-traumatic stress disorder (PTSD), and associated with poor clinical outcomes. Few studies have examined sleep quantitative electroencephalography (qEEG), a technique able to detect subtle differences that polysomnography does not capture. We hypothesized that greater high-frequency qEEG would reflect 'hyperarousal' in combat veterans with PTSD (n = 16) compared to veterans without PTSD (n = 13). EEG power in traditional EEG frequency bands was computed for artifact-free sleep epochs across an entire night. Correlations were performed between qEEG and ratings of PTSD symptoms and combat exposure. The groups did not differ significantly in whole-night qEEG measures for either rapid eye movement (REM) or non-REM (NREM) sleep. Non-significant medium effect sizes suggest less REM beta (opposite to our hypothesis), less REM and NREM sigma and more NREM gamma in combat veterans with PTSD. Positive correlations were found between combat exposure and NREM beta (PTSD group only), and REM and NREM sigma (non-PTSD group only). Results did not support global hyperarousal in PTSD as indexed by increased beta qEEG activity. The correlation of sigma activity with combat exposure in those without PTSD and the non-significant trend towards less sigma activity during both REM and NREM sleep in combat veterans with PTSD

suggests that differential information processing during sleep may characterize combat-exposed military veterans with and without PTSD.

Egner, T., Strawson, E., & Gruzelier, J. H. (2002). EEG signature and phenomenology of alpha/theta neurofeedback training versus mock feedback. *Applied Psychophysiology & Biofeedback*, 27(4), 261-270. Alpha/theta (a/t) neurofeedback training has in the past successfully been used as a complementary therapeutic relaxation technique in the treatment of alcoholism. In spite of positive clinical outcomes, doubts have been cast on the protocol's specificity when compared to alternative relaxation regimes. This study investigated the basic tenet underlying the a/t training rationale, that accurate a/t feedback representation facilitates the generation of these frequency components. Two groups of healthy volunteers were randomly assigned to either (a) real contingent a/t feedback training or (b) a noncontingent mock feedback control condition. The groups were compared on measures of theta/alpha (t/a) ratios within and across training sessions, as well as activational self-report scales after each session. The contingent a/t feedback group displayed significant within-session t/a ratio increments not evident in the mock control group, as well as higher overall t/a ratios in some but not all of the training sessions. No differences were found between the groups in terms of subjective activational phenomenology, in that both groups reported significantly lower levels of activation after training sessions. The data demonstrate that irrespective of considerations of clinical relevance, accurate a/t neurofeedback effectively facilitates production of higher within-session t/a ratios than do noncontingent feedback relaxation.

Garrett, B. L., & Silver, M. P. (1976). The use of EMG and alpha biofeedback to relieve test anxiety in college students. Chapter in I. Wickramasekera (Ed.), Biofeedback, Behavior Therapy, and Hypnosis. Chicago: Nelson-Hall.

Gruzelier, JH., Thompson, T., Redding, E., Brandt, R. & Steffert, T. (2014). Application of alpha/theta neurofeedback and heart rate variability training to young contemporary dancers: State anxiety and creativity. Int J Psychophysiol Jul:93(1). 105-111. As one in a series on the impact of EEG-neurofeedback in the performing arts, we set out to replicate a previous dance study in which alpha/theta (A/T) neurofeedback and heart rate variability (HRV) biofeedback enhanced performance in competitive ballroom dancers compared with controls. First year contemporary dance conservatoire students were randomised to the same two psychophysiological interventions or a choreology instruction comparison group or a no-training control group. While there was demonstrable neurofeedback learning, there was no impact of the three

interventions on dance performance as assessed by four experts. However, HRV training reduced anxiety and the reduction correlated with improved technique and artistry in performance; the anxiety scale items focussed on autonomic functions, especially cardiovascular activity. In line with the putative impact of hypnogogic training on creativity A/T training increased cognitive creativity with the test of unusual uses, but not insight problems. Methodological and theoretical implications are considered.

Hammond, D. C. (2005). Neurofeedback with anxiety and affective disorders. ***Child & Adolescent Psychiatric Clinics of North America*****, 14(1), 105-123.** A robust body of neurophysiologic research is reviewed on functional brain abnormalities associated with depression, anxiety, and obsessive-compulsive disorder. A review of more recent research finds that pharmacologic treatment may not be as effective as previously believed. A more recent neuroscience technology, electroencephalographic (EEG) biofeedback (neurofeedback), seems to hold promise as a methodology for retraining abnormal brain wave patterns. It has been associated with minimal side effects and is less invasive than other methods for addressing biologic brain disorders. Literature is reviewed on the use of neurofeedback with anxiety disorders, including posttraumatic stress disorder and obsessive-compulsive disorder, and with depression. Case examples are provided.

Hammond, D. C. (2003). QEEG-guided neurofeedback in the treatment of obsessive compulsive disorder. ***Journal of Neurotherapy*****, 7(2), 25-52.** Introduction. Blinded, placebo-controlled research (e.g., Sterman, 2000) has documented the ability of brainwave biofeedback to recondition brain wave patterns. Neurofeedback has been used successfully with uncontrolled epilepsy, ADD/ADHD, learning disabilities, anxiety, and head injuries. However, nothing has been published on the treatment of obsessive-compulsive disorder (OCD) with neurofeedback.
Method. Quantitative EEGs were gathered on two consecutive OCD patients who sought treatment. This assessment guided protocol selection for subsequent neurofeedback training. Results. Scores on the Yale-Brown Obsessive-Compulsive Scale and the Padua Inventory normalized following treatment. An MMPI was administered pre-post to one patient, and she showed dramatic improvements not only in OCD symptoms, but also in depression, anxiety, somatic symptoms, and in becoming extroverted rather than introverted and withdrawn. Discussion. In follow-ups of the two cases at 15 and 13 months after completion of treatment, both patients were maintaining improvements in OCD symptoms as measured by the Padua Inventory and as externally validated through contacts with family members. Since research has found that pharmacologic treatment of OCD produces only very modest improvements and behavior therapy

utilizing exposure with response prevention is experienced as quite unpleasant and results in treatment dropouts, neurofeedback appears to have potential as a new treatment modality.

Hardt, J. V., & Kamiya, J. (1978). Anxiety change through electroencephalographic alpha feedback seen only in high anxiety subjects. *Science*, 201, 79-81. Subjects who were either high or low in trait anxiety used alpha feedback to increase and to decrease their electroencephalographic alpha activity. The alpha changes were tightly linked to anxiety changes, but only in high anxiety subjects (for whom anxiety was reduced in proportion to alpha increases, and was increased in proportion to alpha suppression). Low trait-anxiety subjects were superior at both enhancement and suppression training, but their alpha changes were not related to anxiety changes. In both groups, anxiety changes were generally unrelated to either resting levels or changes in frontalis electromyograms and respiration rate. These results suggest that long-term alpha feedback training (at least 5 hours) may be useful in anxiety therapy.

Holmes, D. S., Burish, T. G., & Frost, R. O. (1980). Effects of instructions and biofeedback in EEG-alpha production and the effects of EEG-alpha biofeedback training for controlled arousal in a subsequent stressful situation. *Journal of Research in Personality*, 14(2), 212-223. No abstract found.

Huang,-Storms, L., Bodenhamer-Davis, E., Davis, R., & Dunn, J. (2006). QEEG-guided neurofeedback for children with histories of abuse and neglect: Neurodevelopmental rationale and pilot study. *Journal of Neurotherapy*, 10(4), 3-16. Background. Poor self-regulation of arousal is central to the behavioral difficulties experienced by children with traumatic caretaker attachment histories. EEG biofeedback teaches children to self-regulate brain rhythmicity, which may in turn affect global improvements in the areas of attention, aggression, impulse control, and trust formation. Research literature reports successful use of neurofeedback for children with ADHD, autism, asthma, stroke, and migraine. This study extends current research by investigating the effectiveness of neurofeedback in reducing behavioral problems commonly observed in abused/neglected children. Methods. Treatment records of twenty adopted children with histories of removal from their biological home by Child Protective Services were obtained from a private neurofeedback practice. All of the children were assessed prior to treatment using the Child Behavior Checklist (CBCL) and the Test of Variables of Attention (TOVA) and again after 30 sessions of individualized, qEEG-guided neurofeedback. Results. T-test analysis of pre- and post-scores on the CBCL showed significant changes in the areas of externalizing problems, internalizing

problems, social problems, aggressive behavior, thought problems, delinquent behavior, anxiety/depression, and attention problems ($p < .05$). TOVA omission error, commission error, and variability scores also improved significantly following neurofeedback training ($p < .05$). Some pre-treatment qEEG patterns common to this group of children were identified. Conclusions. The CBCL and TOVA score improvements observed in this study indicate that neurofeedback is effective in reducing behavioral, emotional, social, and cognitive problems in children with histories of neglect and/or abuse.

Kerson, C., Sherman, R.A., Kozlowski, G.P. (2009). Alpha suppression and symmetry training for generalized anxiety disorders. Journal of Neurotherapy,13(3) 146-158. Alpha suppression and symmetry training for generalized anxiety symptoms. Journal of Neurotherapy 13(3), 146 - 155. Introduction. Twenty-eight anxious adults were assessed for frontal lobe alpha asymmetry, a brain state associated with depression and anxiety. Fifteen of the 28 exhibited significant asymmetry and 12 agreed to participate in a biofeedback program addressed at reducing frontal alpha asymmetry. Method. The program consisted of earlobe temperature biofeedback (ETB) and two forms of neurofeedback, alpha suppression and alpha symmetry training. Individuals were instructed to warm their right earlobe for six sessions, and half succeeded, though success was not required to advance to the next stage of training. For subsequent EEG training, two anterior sites were selected on the basis of poor alpha coherence. Individuals were trained to reduce alpha magnitude at these sites by 10% for 30 min or more, which took from 6 to 16 sessions to achieve. Once successful with alpha suppression, individuals were trained to improve alpha symmetry between the sites by 15% for 30 min or more. Results. This feat took 8 to 32 sessions to achieve, and eventually all eight individuals were able to reduce alpha asymmetry. The State-Trait Anxiety Inventory (STAI) was used to measured anxiety levels after each training type and both state and trait scores significantly improved by a 6-month follow-up. Conclusion. Participants also completed a daily shortened version of the STAI, which indicated that anxiety improved after neurofeedback but not after ETB.

Kleutsch, RC., Ros, T., Theberge, J., Frewen, PA., Calhoun, VD., Schmal, C., Jetly, R. & Lanius, RA. (2014). Plastic modulation of PTSD resting state networks and subjective wellbeing by EEG neurofeedback. Acta Psychiatr Scand Aug:130(2). 123-36. OBJECTIVE: Electroencephalographic (EEG) neurofeedback training has been shown to produce plastic modulations in salience network and default mode network functional connectivity in healthy individuals. In this study, we investigated whether a single session of neurofeedback training aimed at the voluntary reduction of alpha rhythm (8-12 Hz) amplitude would be related to differences in EEG network oscillations, functional

MRI (fMRI) connectivity, and subjective measures of state anxiety and arousal in a group of individuals with post-traumatic stress disorder (PTSD). METHOD: Twenty-one individuals with PTSD related to childhood abuse underwent 30 min of EEG neurofeedback training preceded and followed by a resting-state fMRI scan. RESULTS: Alpha desynchronizing neurofeedback was associated with decreased alpha amplitude during training, followed by a significant increase ('rebound') in resting-state alpha synchronization. This rebound was linked to increased calmness, greater salience network connectivity with the right insula, and enhanced default mode network connectivity with bilateral posterior cingulate, right middle frontal gyrus, and left medial prefrontal cortex.

CONCLUSION:
Our study represents a first step in elucidating the potential neurobehavioural mechanisms mediating the effects of neurofeedback treatment on regulatory systems in PTSD. Moreover, it documents for the first time a spontaneous EEG 'rebound' after neurofeedback, pointing to homeostatic/compensatory mechanisms operating in the brain.

Kopřivová J, Congedo M, Raszka M, Praško J, Brunovský M, Horáček J. (2013). Prediction of treatment response and the effect of independent component neurofeedback in obsessive-compulsive disorder: a randomized, sham-controlled, double-blind study. Neuropsychobiology. 2013;67(4):210-23. doi: 10.1159/000347087. Epub 2013 Apr 27. Aims: The goal of this study was to assess the effect of independent component neurofeedback (NFB) on EEG and clinical symptoms in patients with obsessive-compulsive disorder (OCD). Subsequently, we explored predictors of treatment response and EEG correlates of clinical symptoms. Methods: In a randomized, double-blind, parallel design, 20 inpatients with OCD underwent 25 sessions of NFB or sham feedback (SFB). NFB aimed at reducing EEG activity in an independent component previously reported abnormal in this diagnosis. Resting-state EEG recorded before and after the treatment was analyzed to assess its posttreatment changes, relationships with clinical symptoms and treatment response. Results: Overall, clinical improvement in OCD patients was not accompanied by EEG change as assessed by standardized low-resolution electromagnetic tomography and normative independent component analysis. Pre- to posttreatment comparison of the trained component and frequency did not yield significant results; however, in the NFB group, the nominal values at the downtrained frequency were lower after treatment. The NFB group showed significantly higher percentage reduction of compulsions compared to the SFB group ($p = 0.015$). Pretreatment higher amount of delta (1-6 Hz) and low alpha oscillations as well as a lower amount of high beta activity predicted a worse treatment

outcome. Source localization of these delta and high beta oscillations corresponded with previous EEG resting-state findings in OCD patients compared to healthy controls. Conclusion: Independent component NFB in OCD proved useful in percentage improvement of compulsions. Based on our correlation analyses, we hypothesize that we targeted a network related to treatment resistance.

Mills, G. K., & Solyom, L. (1974). Biofeedback of EEG alpha in the treatment of obsessive ruminations: An exploration. *Journal of Behaviour Therapy & Experimental Psychiatry*, 5, 37-41. The enhancement of EEG alpha through various meditative techniques and biofeedback has been shown to correlate with alterations in mental as well as muscular activity towards a state of relaxation. We thought that such mental relaxation might be reciprocally inhibitory to ruminative activity characteristic of the obsessive neurotic. Five ruminating obsessives were given 7-20 biofeedback training sessions to learn control of EEG alpha. Results indicate that (1) some obsessives can learn EEG control; (2) special augmented instructions seem no better than standard, minimal instructions in aiding *S*s to produce alpha; (3) subjective states during alpha are reported as relaxed, daydreaming and not thinking; and (4) although difficult to generalize beyond the feedback situation, virtually no ruminations occur during alpha regardless of the amount of alpha produced. Further study is indicated before a treatment program can be considered.

Moore, N. C. (2000). A review of EEG biofeedback treatment of anxiety disorders. *Clinical Electroencephalography*, 31(1), 1-6. Alpha, theta and alpha-theta enhancements are effective treatments of the anxiety disorders (Table 1). Alpha suppression is also effective, but less so (Table 2). Perceived success in carrying out the task plays an important role in clinical improvement. Research is needed to find out how much more effective they are than placebo, and which variables are important for efficacy. Variables needing study are: duration of treatment, type and severity of anxiety, number and type of EEG waveforms used, pretreatment with other kinds of feedback, position and number of electrodes, and presence of concomitant medication.

Norris, S. L., Lee, C-T., Burshteyn, D., & Cea-Aravena, J. (2001). The effects of performance enhancement training on hypertension, human attention, stress, and brain wave patterns: A case study. *Journal of Neurotherapy*, 4(3), 29-44. Background: The purpose of this study was to evaluate the effects of alpha-increase neurofeedback training (Performance Enhancement Training) on blood pressure, stress reduction, attention, and observe changes in brainwave patterns. A forty-nine-year-old male college

student diagnosed with essential hypertension controlled by medication had undergone twenty-six sessions of alpha-increase biofeedback (8-13 Hz) at PZ electrode site for a period of 15 weeks. Method: Pre- and post-blood pressure measurements were taken for every session. At the beginning of week number eight, the participant discontinued his medication as advised by his physician. Pre- and post-visual TOVA CPT test was administered to assess the changes in accuracy, reaction time (RT), and RT variability. Osterkamp and Press Self-Assessment Stress Inventory was administered before and after training to assess the level of stress. QEEG evaluation was conducted prior, as well as upon completion of the study. Results: Mean Arterial Blood Pressure (MAP) yielded statistically significant results between pre- and post-sessions within participant blood pressure measurements. The participant's systolic and diastolic blood pressures during the first thirteen sessions were not significantly different from those of the last thirteen sessions when his medication was discontinued, suggesting his ability to control his blood pressure within normal limits without the use of medication. The results of the TOVA test clearly indicate an improvement in individuals' reaction time and the reaction time variability. The results of the Osterkamp and Press Self-Assessment Stress Inventory indicated an improvement in two of the scales: Work and Social Life. Statistical analysis showed that before and after QEEG evaluations were within normal limits. Discussion: The mechanism through which Performance Enhancement Training simultaneously affects blood pressure, reaction time (RT), and variability needs further investigation. However, the positive changes in the measured variables appear to be a function of enhanced self-awareness that leads to the improved self-regulation.

Peeters, F., Ronner, J., Bodar, L., van Os, J. & Louisberg, R. (2013). Validation of a neurofeedback paradigm: Manipulating frontal EEG alpha-activity and its impact on mood. Int J Psychophysiol. doi: 10.1016/j.ijpsycho.2013.06.010. It is claimed that neurofeedback (NF) is an effective treatment for a variety of psychiatric disorders. NF, within an operant conditioning framework, helps individuals to regulate cortical electroencephalographic (EEG) activity while receiving feedback from a visual or acoustic signal. For example, changing asymmetry between left and right frontal brain alpha activity by NF, is claimed to be an efficacious treatment for major depressive disorder. However, the specificity of this intervention in occasioning electrophysiological changes at target locations and target wave-frequencies, and its relation to changes in mood, has not been established. During a single session of NF, it was tested if the balance between left and right frontal alpha-activity could be changed, regardless of direction, in 40 healthy females. Furthermore, we investigated whether this intervention was electrophysiologically specific and if it was associated with changes in mood. Participants were able to decrease or increase frontal alpha-asymmetry during the

intervention. However, no changes in mood were observed. (*Note from bibliographer: one session would rarely provide changes in behavior*). Changes in EEG activity were specific in terms of location and wave-frequency.

Peniston, E. G., & Kulkosky, P. J. (1991). Alpha-theta brainwave neuro-feedback therapy for Vietnam veterans with combat-related post-traumatic stress disorder. *Medical Psychotherapy*, 4, 47-60. The Minnesota Personality Inventory (MMPI) was used to assess personality changes in Vietnam combat veterans with PTSD after either traditional medical treatment (TC) or alpha-theta brainwave neuro-feedback therapy (BWT). Application of brainwave training for thirty 30-minute sessions resulted in decreases in MMPI T-scores on clinical scales labeled hypochondriasis, depression, hysteria, psychopathis deviate masculinity-femininity, paranoia, psychasthenia, schizophrenia, hypomania and social introversion-extroversion. The traditional medical control group showed decreases in T-scores only on the scale labeled schizophrenia. All 14 BWT patients initially receiving psychotropic medication reduced their dosages after treatment, but only one of thirteen TC patients reduced dosage. A thirty-month follow up study showed that all fourteen TC patients had relapsed, in contract to only three of fifteen BWT patients. These findings indicate that application of alpha-theta brainwave training I a more efficacious treatment modality in the treatment of PTSD and preventative of relapse.

Peniston, E. G., Marrinan, D. A., Deming, W. A., & Kulkosky, P. J. (1993). EEG alpha-theta brainwave synchronization in Vietnam theater veterans with combat-related post-traumatic stress disorder and alcohol abuse. *Advances in Medical Psychotherapy*, 6, 37-50. No abstract available.

Putnam, J. (2000). The effects of brief, eyes-open alpha brain wave training with audio and video relaxation induction on the EEG of 77 Army reservists. *Journal of Neurotherapy,* 4(1), 17-28. Background: Recently, psychologist Barry Sterman of the UCLA School of Medicine became involved in measuring the brain wave activity of pilots engaged in a variety of tasks for the purpose of identifying the brain wave correlates of peak performance under different load conditions. Sterman found that during a manageable periodic challenge the brain waves exhibited, in parietal areas, a consistent cycling between resting state alpha (when in the attentive readiness state) and an alpha desynchronized, elevated low beta state when engaged in the response mode. As the tasks came closer together, hence allowing for no alpha respite, there was a deterioration in performance accompanied by an increase in theta activity. In this paper, the effects of brief, eyes-open alpha brain wave enhancement training will be

examined for the general purpose of suggesting possible methods for increasing functional integrity and cortical flexibility through increased alpha brain wave production. Methods: The subjects were 77 U.S. Army reservists. The EEG biofeedback system used was the BioIntegrator manufactured by the Bio-Research Institute. Alpha enhancement training was employed with electrode placement at Pz. Results: It was found that eyes-open alpha enhancement training resulted in substantial increases in activity in the feedback band (alpha) with smaller increases in low beta and decreases in theta. This is quite a different result than one would expect from general "relaxation" training that is usually accomplished with eyes closed and yields substantial increases in both alpha and theta. Conclusion: When engaged in this training, even for brief periods, the EEG moves in a direction quite different to that of Sterman's burnout profile. It would be of interest to demonstrate rigorously that the training could, if administered preventatively, diminish poor performance in persons performing tasks that demand prolonged periods of external focus under high load conditions.

Raymond, J., Varney, C., Parkinson, L. A., & Gruzelier, J.H. (2005). The effects of alpha/theta neurofeedback on personality and mood. ***Brain Research & Cognitive Brain Research*****, 23(2-3), 287-292.** Alpha/theta neurofeedback has been shown to be successful both in treating addictions and in enhancing artistry in music students. How its effects are mediated are not yet clear. The present study aimed to test the hypothesis that alpha/theta neurofeedback works inter alia by normalising extreme personality and raising feelings of wellbeing. 12 participants with high scores for Withdrawal (as measured by the PSQ) were given either alpha/theta neurofeedback or mock feedback and their personality and mood were assessed. Withdrawal scores on the PSQ-80 were not found to change in either group but significant effects were found for the Profile Of Mood States (POMS), with real feedback producing higher overall scores than mock feedback ($P = 0.056$). Real feedback caused participants to feel significantly more energetic ($P < 0.01$) than did mock feedback. Sessions of real feedback made participants feel more composed ($P < 0.01$), agreeable ($P < 0.01$), elevated ($P < 0.01$) and confident ($P < 0.05$), whilst sessions of mock feedback made participants feel more tired ($P < 0.05$), yet composed ($P < 0.01$). These findings suggest that, whilst 9 sessions of alpha/theta neurofeedback was insufficient to change personality, improvements in mood may provide a partial explanation for the efficacy of alpha/theta neurofeedback.

Rice, K. M., Blanchard, E. B., & Purcell, M. (1993). Biofeedback treatments of generalized anxiety disorder: Preliminary results. ***Biofeedback & Self-Regulation,*** **18, 93-105.** Forty-five individuals with generalized anxiety (38 with GAD as defined by DSM-

III) were randomized to 4 treatment conditions or a waiting list control. Patients received 8 sessions of either frontal EMG biofeedback, biofeedback to increase EEG alpha, biofeedback to decrease EEG alpha, or a pseudomeditation control condition. All treated subjects showed significant reductions in STAI-Trait Anxiety and psychophysiologic symptoms on the Psychosomatic Symptom Checklist. Only alpha-increase biofeedback subjects showed significant reductions in heart rate reactivity to stressors at a separate psychophysiological testing session. Decreased self-report of anxiety was maintained at 6 weeks post treatment.

Scheinost D, Stoica T, Saksa J, Papademetris X, Constable RT, Pittenger C & Hampson M. (2013). Orbitofrontal cortex neurofeedback produces lasting changes in contamination anxiety and resting-state connectivity. Transl Psychiatry. 2013 Apr 30;3:e250. doi: 10.1038/tp.2013.24. Anxiety is a core human emotion but can become pathologically dysregulated. We used functional magnetic resonance imaging (fMRI) neurofeedback (NF) to noninvasively alter patterns of brain connectivity, as measured by resting-state fMRI, and to reduce contamination anxiety. Activity of a region of the orbitofrontal cortex associated with contamination anxiety was measured in real time and provided to subjects with significant but subclinical anxiety as a NF signal, permitting them to learn to modulate the target brain region. NF altered network connectivity of brain regions involved in anxiety regulation: subjects exhibited reduced resting-state connectivity in limbic circuitry and increased connectivity in the dorsolateral prefrontal cortex. NF has been shown to alter brain connectivity in other contexts, but it has been unclear whether these changes persist; critically, we observed changes in connectivity several days after the completion of NF training, demonstrating that such training can lead to lasting modifications of brain functional architecture. Training also increased subjects' control over contamination anxiety several days after the completion of NF training. Changes in resting-state connectivity in the target orbitofrontal region correlated with these improvements in anxiety. Matched subjects undergoing a sham feedback control task showed neither a reorganization of resting-state functional connectivity nor an improvement in anxiety. These data suggest that NF can enable enhanced control over anxiety by persistently reorganizing relevant brain networks and thus support the potential of NF as a clinically useful therapy.

Simkin, DR., Thatcher, RW. & Lubar, J. (2014). Quantitative EEGB and Neurofeedback in Children and adolescents: Anxiety disorders, depressive disorders, comorbid addiction and attention-deficit/hyperactivity disorder and brain injury. *Child and Adolescent Psychiatric Clinics of North America*:23(3). 427-464. This article explores the science surrounding neurofeedback. Both surface neurofeedback (using 2-4

electrodes) and newer interventions, such as real-time z-score neurofeedback (electroencephalogram [EEG] biofeedback) and low-resolution electromagnetic tomography neurofeedback, are reviewed. The limited literature on neurofeedback research in children and adolescents is discussed regarding treatment of anxiety, mood, addiction (with comorbid attention-deficit/hyperactivity disorder), and traumatic brain injury. Future potential applications, the use of quantitative EEG for determining which patients will be responsive to medications, the role of randomized controlled studies in neurofeedback research, and sensible clinical guidelines are considered.

Sittenfeld, P., Budzynski, T. H., & Stoyva, J. M. (1976). ***Differential shaping of EEG theta rhythms*****. Biofeedback & Self-Regulation, 1, 31-46.** Heart rate, EEG, frontal EMG, and forearm EMG were recorded in 20 subjects for 3 baseline, 8 feedback, and 2 postbaseline sessions in order to compare two biofeedback methods of teaching subjects to increase theta EEG activity. Subjects were divided into high- and low-EMG groups. Five high-EMG subjects, and 5 low-EMG subjects then received 8 sessions of strictly theta feedback. The remaining 10 subjects, 5 from the high-EMG group, and 5 from the low-EMG group, received a "graduated" training, which involved shaping the target response. This procedure consisted of 4 initial sessions of EMG feedback, followed by a second phase consisting of 4 sessions of theta feedback. Results showed a clear relationship between subjects' baseline frontal EMG levels and the effect of the training methods. Although subjects with high-EMG baseline increased their theta output only with the two-phase training, subjects with low-EMG baseline levels performed better when given theta feedback only. This result shows not only that amounts of theta can be reliably increased, but that training techniques should be adapted to the physiological characteristics of the individual--in this case, baseline levels of frontal EMG levels.

Sokhadze, E., Singh, S., Stewart, C., Hollifield, M., El-Baz, A., Tasman, A. (2008). Attentional bias to drug- and stress-related pictorial cues in cocaine addiction comorbid with Posttraumatic Stress Disorder. ***Journal of Neurotherapy*****;12(4), 205 - 225**. Introduction. Cocaine addiction places a specific burden on mental health services through its comorbidity with other psychiatric disorders. Treatment of patients with cocaine abuse is more complicated when addiction is co-occurring with posttraumatic stress disorder (PTSD). This study used dense-array event-related potential (ERP) technique to investigate whether the patients with this form of dual diagnosis display excessive reactivity to both trauma and drug cues as compared to neutral cues. Cue reactivity refers to a phenomenon in which individuals with a history of drug dependence exhibit verbal, physiological, and behavioral responses to cues associated with their preferred substance of abuse. This study explores ERP differences associated with cue-

related responses to both drug and trauma cues in a three-category oddball task using neutral, drug-related, and trauma-related pictorial stimuli. Methods. The study was conducted on 14 cocaine dependent participants, 11 participants with cocaine-dependence comorbid with PTSD, and 9 age- and gender-matched control subjects. A 128-channel Electrical Geodesics EEG system was used to record ERP during the visual three-category oddball task with three categories (neutral, drug, stress) of affective pictures. Results. Patients with cocaine dependence and PTSD, as compared to patients with only cocaine addiction and control participants, showed excessive cue reactivity to both drug- and trauma-related visual stimuli. Most profound differences were found in the amplitude and latency of frontal P3a, and centro-parietal P3b ERP components. Group differences were found as well between patients with cocaine abuse (both addiction-only and dual diagnosis groups) versus controls on most ERP measures for drug-related cues. Conclusion. We propose that the employed ERP cue reactivity variables could be used as valuable functional outcome measures in dually diagnosed drug addicts undergoing behavioral treatment.

Thomas, J. E., & Sattlberger, B. A. (1997). Treatment of chronic anxiety disorder with neurotherapy: A case study. ***Journal of Neurotherapy,*** **2(2), 14-19.** The objective of the present case study is to report the effects of alpha-decrease biofeedback training on a patient diagnosed with Anxiety Disorder. Three Minnesota Multiphasic Personality Inventories (MMPI and MMPI-2) were used as objective measures of treatment efficacy. Following 15 sessions of slow wave inhibit/fast wave increase EEG feedback training, the patient reported a significant reduction in anxiety-related symptoms. At three-year follow-up, results of an MMPI-2 showed all clinical scales within normal range. In addition, self-reports confirmed that the patient was symptom free. After treating the patient with several other clinical modalities, only the alpha-decrease feedback training produced effective, long-term improvement of symptoms.

Vanathy, S., Sharma, P. S. V. N., & Kumar, K. B. (1998). The efficacy of alpha and theta neurofeedback training in treatment of generalized anxiety disorder. ***Indian Journal of Clinical Psychology,*** **25(2), 136-143.** No abstract found

Vasa, RA., Carroll, LM., Nozzolillio, AA., Mahajan, R., Mazurek, MO., Bennett, AE., Wink, LK. & Bernal, MP. (2014). A systematic review of treatments for anxiety in youth with autism spectrum disorders. J Autism Dev Disord. July 2014 Early e-pub. This study systematically examined the efficacy and safety of psychopharmacological and non-psychopharmacological treatments for anxiety in youth with autism spectrum disorders (ASD). Four psychopharmacological, nine cognitive behavioral therapy (CBT), and two

alternative treatment studies met inclusion criteria. Psychopharmacological studies were descriptive or open label, sometimes did not specify the anxiety phenotype, and reported behavioral activation. Citalopram and buspirone yielded some improvement, whereas fluvoxamine did not. Non-psychopharmacological studies were mainly randomized controlled trials (RCTs) with CBT demonstrating moderate efficacy for anxiety disorders in youth with high functioning ASD. Deep pressure and neurofeedback provided some benefit. All studies were short-term and included small sample sizes. Large scale and long term RCTs examining psychopharmacological and non-psychopharmacological treatments are sorely needed.

Watson, C. G., Herder, J., & Passini, F. T. (1978). Alpha biofeedback therapy in alcoholics: An 18-month follow-up. *Journal of Clinical Psychology*, 34(2), 765-769. In an earlier study on patients with alcohol problems, an experimental group given 10 hour-long alpha biofeedback training sessions showed greater improvement on State and Trait Anxiety scores than did a control sample. In the present study an 18-month follow-up was done on those Ss. The differences between the experimentals and controls in State and Trait Anxiety after 18 months were essentially identical to the differences between them immediately after treatment, which indicates that alpha training had long-range therapeutic effects. A difference between the groups on the Alcohol Rehabilitation Followup Questionnaire also suggested that alpha training may have been associated with some reduction in alcohol consumption as well.

AUTISM SPECTRUM DISORDERS

Baruth, J., Casanova, M., Sears, L. & Sokhadze, E., (2010). Early-stage visual processing abnormalities in high-functioning autism spectrum disorder (ASD). *Translational Neuroscience*, 1(2), 177-187. It has been reported that individuals with autism spectrum disorder (ASD) have abnormal responses to the sensory environment. For these individuals sensory overload can impair functioning, raise physiological stress, and adversely affect social interaction. Early-stage (i.e. within 200 ms of stimulus onset) auditory processing abnormalities have been widely examined in ASD using event-related potentials (ERP), while ERP studies investigating early-stage visual processing in ASD are less frequent. We wanted to test the hypothesis of early-stage visual processing abnormalities in ASD by investigating ERPs elicited in a visual oddball task using illusory figures. Our results indicate that individuals with ASD have abnormally large cortical responses to task irrelevant stimuli over both parieto-occipital and frontal regions-of-interest (ROI) during early stages of visual processing compared to the control group. Furthermore, ASD patients showed signs of an overall disruption in stimulus discrimination, and had a significantly higher rate of motor response errors.

Baruth, J., Williams, E., Sokhadze, E., El-Baz, A., Sears, L., & Casanova, M.F. (2011). Repetitive transcranial stimulation (rTMS) improves electroencephalographic and behavioral outcome measures in autism spectrum disorders (ASD). *Autism Science Digest*, 1(1), 52-57. No abstract.

Baruth, J., Casanova, M., El-Baz, A., Horrell, T., Mathai, G., Sears, L., & Sokhadze, E. (2010). Low-frequency repetitive transcranial magnetic stimulation modulates evoked-gamma frequency oscillations in autism spectrum disorders. *Journal of Neurotherapy*, 14 (3), 179-194. In our previous study on individuals with autism spectrum disorder (ASD) (Sokhadze et al., Appl Psychophysiol Biofeedback 34:37-51, 2009a) we reported abnormalities in the attention-orienting frontal event-related potentials (ERP) and the sustained-attention centro-parietal ERPs in a visual oddball experiment. These results suggest that individuals with autism over-process information needed for the successful differentiation of target and novel stimuli. In the present study we examine the effects of low-frequency, repetitive Transcranial Magnetic Stimulation (rTMS) on novelty processing as well as behavior and social functioning in 13 individuals with ASD. Our hypothesis was that low-frequency rTMS application to dorsolateral prefrontal cortex (DLFPC) would result in an alteration of the cortical excitatory/inhibitory balance

through the activation of inhibitory GABAergic double bouquet interneurons. We expected to find post-TMS differences in amplitude and latency of early and late ERP components. The results of our current study validate the use of low-frequency rTMS as a modulatory tool that altered the disrupted ratio of cortical excitation to inhibition in autism. After rTMS the parieto-occipital P50 amplitude decreased to novel distracters but not to targets; also the amplitude and latency to targets increased for the frontal P50 while decreasing to non-target stimuli. Low-frequency rTMS minimized early cortical responses to irrelevant stimuli and increased responses to relevant stimuli. Improved selectivity in early cortical responses lead to better stimulus differentiation at later-stage responses as was made evident by our P3b and P3a component findings. These results indicate a significant change in early, middle-latency and late ERP components at the frontal, centro-parietal, and parieto-occipital regions of interest in response to target and distracter stimuli as a result of rTMS treatment. Overall, our preliminary results show that rTMS may prove to be an important research tool or treatment modality in addressing the stimulus hypersensitivity characteristic of autism spectrum disorders.

Casanova, M., Baryth, J., El-Baz, A., Tasman, A., Sears, L., & Sokhadze, E. (2012). Repetitive transcranial magnetic stimulation (rTMS) modulates event-related potential (ERP) indices of attention in autism. *Translational Neuroscience*: 3(2) 170-180. In our previous study on individuals with autism spectrum disorder (ASD) (Sokhadze et al., Appl Psychophysiol Biofeedback 34:37-51, 2009a) we reported abnormalities in the attention-orienting frontal event-related potentials (ERP) and the sustained-attention centro-parietal ERPs in a visual oddball experiment. These results suggest that individuals with autism over-process information needed for the successful differentiation of target and novel stimuli. In the present study we examine the effects of low-frequency, repetitive Transcranial Magnetic Stimulation (rTMS) on novelty processing as well as behavior and social functioning in 13 individuals with ASD. Our hypothesis was that low-frequency rTMS application to dorsolateral prefrontal cortex (DLFPC) would result in an alteration of the cortical excitatory/inhibitory balance through the activation of inhibitory GABAergic double bouquet interneurons. We expected to find post-TMS differences in amplitude and latency of early and late ERP components. The results of our current study validate the use of low-frequency rTMS as a modulatory tool that altered the disrupted ratio of cortical excitation to inhibition in autism. After rTMS the parieto-occipital P50 amplitude decreased to novel distracters but not to targets; also the amplitude and latency to targets increased for the frontal P50 while decreasing to non-

target stimuli. Low-frequency rTMS minimized early cortical responses to irrelevant stimuli and increased responses to relevant stimuli. Improved selectivity in early cortical responses lead to better stimulus differentiation at later-stage responses as was made evident by our P3b and P3a component findings. These results indicate a significant change in early, middle-latency and late ERP components at the frontal, centro-parietal, and parieto-occipital regions of interest in response to target and distracter stimuli as a result of rTMS treatment. Overall, our preliminary results show that rTMS may prove to be an important research tool or treatment modality in addressing the stimulus hypersensitivity characteristic of autism spectrum disorders.

Casanova, M., Mott, M., & Sokhadze, E. (2012) Neuropathology of autism: Review of current literature. *Siberian Journal of Special Education* (in press)(in Russian).

Coben R, Linden M, Myers TE. (2012). Neurofeedback for autistic spectrum disorder: a review of the literature. *Appl Psychophysiol Biofeedback*. 2010 Mar;35(1):83-105. There is a need for effective interventions to address the core symptoms and problems associated with autistic spectrum disorder (ASD). Behavior therapy improves communication and behavioral functioning. Additional treatment options include psychopharmacological and biomedical interventions. Although these approaches help children with autistic problems, they may be associated with side effects, risks or require ongoing or long-term treatment. Neurofeedback is a noninvasive approach shown to enhance neuroregulation and metabolic function in ASD. We present a review of the literature on the application of Neurofeedback to the multiple problems associated with ASD. Directions for future research are discussed.

Coben, R., & Myers, T. E. (2010). The relative efficacy of connectivity guided and symptom based EEG biofeedback for autistic disorders. *Applied Psychophysiology & Biofeedback*, 35(1), 13-23. Autism is a neurodevelopmental disorder characterized by deficits in communication, social interaction, and a limited range of interests with repetitive stereotypical behavior. Various abnormalities have been documented in the brains of individuals with autism, both anatomically and functionally. The connectivity theory of autism is a recently developed theory of the neurobiological cause of Autistic symptoms. Different patterns of hyper- and hypo-connectivity have been identified with the use of quantitative electroencephalography (QEEG), which may be amenable to neurofeedback. In this study, we compared the results of two published controlled studies examining the efficacy of neurofeedback in the treatment of autism. Specifically, we examined whether a symptom based approach or an assessment/connectivity guided based approach was more effective. Although both methods demonstrated significant

improvement in symptoms of autism, connectivity guided neurofeedback demonstrated greater reduction on various subscales of the Autism Treatment Evaluation Checklist (ATEC). Furthermore, when individuals were matched for severity of symptoms, the amount of change per session was significantly higher in the Coben and Padolsky (J Neurother 11:5-23, 2007) study for all five measures of the ATEC. Our findings suggest that an approach guided by QEEG based connectivity assessment may be more efficacious in the treatment of autism. This permits the targeting and amelioration of abnormal connectivity patterns in the brains of people who are autistic.

Coben, R., & Pudolsky, I. (2007). Assessment-guided neurofeedback for autistic spectrum disorder. ***Journal of Neurotherapy,*****11(1), 5-23.** Background. Research reviewing the epidemiology of Autism (Medical Research Council, 2001) indicated that approximately 60 per 10,000 children (1/166) are diagnosed with Autistic Spectrum Disorder (ASD). Jarusiewicz (2002) published the only controlled study documenting the effectiveness of neurofeedback for Autism based on one outcome measure. The present study extended these findings with a larger sample size, broader range of assessments, and physiological measures of brain functioning. Methods. Assessment-guided neurofeedback was conducted in 20 sessions for 37 patients with ASD. The experimental and control groups were matched for age, gender, race, handedness, other treatments, and severity of ASD. Results. Improved ratings of ASD symptoms reflected an 89% success rate. Statistical analyses revealed significant improvement in Autistics who received Neurofeedback compared to a wait list control group. Other major findings included a 40% reduction in core ASD symptomatology (indicated by ATEC Total Scores), and 76% of the experimental group had decreased hyper-connectivity. Reduced cerebral hyperconnectivity was associated with positive clinical outcomes in this population. In all cases of reported improvement in ASD symptomatology, positive treatment outcomes were confirmed by neuropsychological and neurophysiological assessment. Conclusions. Evidence from multiple measures has demonstrated that neurofeedback can be an effective treatment for ASD. In this population, a crucial factor in explaining improved clinical outcomes in the experimental group may be the use of assessment-guided neurofeedback to reduce cerebral hyperconnectivity. Implications of these findings are discussed.

Freidrich, EV., Suttie, N., Sivanathan, A., Lim, T., Louchart, S. & Pineda, J. (2014). Brain-computer interface game applications for combined neurofeedback and biofeedback treatment for children on the autism spectrum. Frontiers in Neuroengineering: Jul 3(7). 21. Individuals with autism spectrum disorder (ASD) show

deficits in social and communicative skills, including imitation, empathy, and shared attention, as well as restricted interests and repetitive patterns of behaviors. Evidence for and against the idea that dysfunctions in the mirror neuron system are involved in imitation and could be one underlying cause for ASD is discussed in this review. Neurofeedback interventions have reduced symptoms in children with ASD by self-regulation of brain rhythms. However, cortical deficiencies are not the only cause of these symptoms. Peripheral physiological activity, such as the heart rate and its variability, is closely linked to neurophysiological signals and associated with social engagement. Therefore, a combined approach targeting the interplay between brain, body, and behavior could be more effective. Brain-computer interface applications for combined neurofeedback and biofeedback treatment for children with ASD are currently nonexistent. To facilitate their use, we have designed an innovative game that includes social interactions and provides neural- and body-based feedback that corresponds directly to the underlying significance of the trained signals as well as to the behavior that is reinforced.

Hurt, E., Arnold, AE. & Lofthouse, N. (2014). Quantitative EEG neurofeedback for the treatment of pediatric attention-deficit hyperactivity disorder, autism spectrum disorders, learning disorders and epilepsy. Child and Adolescent Psychiatric Clinics of North America:23(3). 465-86. Neurofeedback (NF) using surface electroencephalographic signals has been used to treat various child psychiatric disorders by providing patients with video/audio information about their brain's electrical activity in real-time. Research data are reviewed and clinical recommendations are made regarding NF treatment of youth with attention deficit/hyperactivity disorder, autism, learning disorders, and epilepsy. Most NF studies are limited by methodological issues, such as failure to use or test the validity of a full-blind or sham NF. The safety of NF treatment has not been thoroughly investigated in youth or adults, although clinical experience suggests reasonable safety.autism

Jarusiewicz, G. (2007). *Use of neurofeedback with autistic spectrum disorders*. Chapter in J. R. Evans (Ed.), Handbook of Neurofeedback. Binghampton, NY: Haworth Medical Press, pp. 321-339.

Jarusiewicz, B. (2002). Efficacy of neurofeedback for children in the autistic spectrum: A pilot study. *Journal of Neurotherapy*, 6(4), 39-49. Background. The efficacy of neurofeedback training was evaluated in 12 children in the autistic spectrum with matched controls, based on established training protocols for other conditions with similar symptoms. Method. Twenty-four autistic children were divided into two groups,

matched by sex, age, and disorder severity. One group received neurofeedback training and the second acted as a control group. Responses to the Autism Treatment Evaluation Checklists (ATEC) and parental assessments of problem behaviors were analyzed to evaluate the effectiveness of neurofeedback training for this condition. Results. Neurofeedback training resulted in a 26% average reduction in total ATEC rated autism symptoms, compared to 3% for the control group. Parental assessments reported improvement in all behavioral categories: socialization, vocalization, anxiety, schoolwork, tantrums, and sleep, compared with minimal changes in the control group. Discussion. Autistic spectrum children who underwent neurofeedback training showed significant improvements in autism symptoms and behaviors. The magnitude of improvement was independent of initial severity or age.

Kouijzer, M. E. UJ., de Moor, J. M. H., Gerrits, B. J. L., Buitelaar, J. K., & van Schie, H. T. (2009). Long-term effects of neurofeedback treatment in autism. *Research in Autism Spectrum Disorders*, 3, 496-501. Previously we demonstrated significant improvement of executive functions and social behavior in children with autism spectrum disorders (ASD) treated with 40 sessions of EEG neurofeedback in a nonrandomized waiting list control group design. In this paper we extend these findings by reporting the long-term results of neurofeedback treatment in the same group of children with ASD after 12 months. The present study indicates maintenance of improvement of executive functions and social behavior after 12 months in comparison with the immediate outcomes. Neurofeedback mediated suppression of theta power is supposed to promote more flexible functioning of the brain by enhancing activation in the medial prefrontal cortex and improving flexibility of activation in the default mode network supporting the improvement of executive functions and theory of mind in ASD.

Pineda, JA., Carrasco, K., Datko, M., Pillen, S. & Schalles, M. (2014). Neurofeedback training produces normalization in behavioral and electrophysical measures of high functioning autism. Philos Trans R Soc Lond B Biol Sci: Apr 28;369. Autism spectrum disorder (ASD) is a neurodevelopmental condition exhibiting impairments in behaviour, social and communication skills. These deficits may arise from aberrant functional connections that impact synchronization and effective neural communication. Neurofeedback training (NFT), based on operant conditioning of the electroencephalogram (EEG), has shown promise in addressing abnormalities in functional and structural connectivity. We tested the efficacy of NFT in reducing symptoms in children with ASD by targeting training to the mirror neuron system (MNS) via modulation of EEG mu rhythms. The human MNS has provided a neurobiological

substrate for understanding concepts in social cognition relevant to behavioural and cognitive deficits observed in ASD. Furthermore, mu rhythms resemble MNS phenomenology supporting the argument that they are linked to perception and action. Thirty hours of NFT on ASD and typically developing (TD) children were assessed. Both groups completed an eyes-open/-closed EEG session as well as a mu suppression index assessment before and after training. Parents filled out pre- and post-behavioural questionnaires. The results showed improvements in ASD subjects but not in TDs. This suggests that induction of neuroplastic changes via NFT can normalize dysfunctional mirroring networks in children with autism, but the benefits are different for TD brains.

Pineda, JA., Friedrich, EV. LaMarca, K. (2014). Neurorehabilitation of social dysfunctions: A model-based neurofeedback approach for low and high-functioning autism. Frontiers in Neuroengineering.: Aug 7(7) 29. Autism Spectrum Disorder (ASD) is an increasingly prevalent condition with core deficits in the social domain. Understanding its neuroetiology is critical to providing insights into the relationship between neuroanatomy, physiology and social behaviors, including imitation learning, language, empathy, theory of mind, and even self-awareness. Equally important is the need to find ways to arrest its increasing prevalence and to ameliorate its symptoms. In this review, we highlight neurofeedback studies as viable treatment options for high-functioning as well as low-functioning children with ASD. Lower-functioning groups have the greatest need for diagnosis and treatment, the greatest barrier to communication, and may experience the greatest benefit if a treatment can improve function or prevent progression of the disorder at an early stage. Therefore, we focus on neurofeedback interventions combined with other kinds of behavioral conditioning to induce neuroplastic changes that can address the full spectrum of the autism phenotype.

Pineda JA, Juavinett A, Datko M. (2012). Self-regulation of brain oscillations as a treatment for aberrant brain connections in children with autism. *Med Hypotheses.* 2012 Dec;79(6):790-8. doi: 10.1016/j. Autism is a highly varied developmental disorder typically characterized by deficits in reciprocal social interaction, difficulties with verbal and nonverbal communication, and restricted interests and repetitive behaviors. Although a wide range of behavioral, pharmacological, and alternative medicine strategies have been reported to ameliorate specific symptoms for some individuals, there is at present no cure for the condition. Nonetheless, among the many incompatible observations about aspects of the development, anatomy, and functionality of the autistic brain, it is widely agreed that it is characterized by widespread aberrant connectivity. Such disordered connectivity, be it increased, decreased, or otherwise compromised, may complicate healthy synchronization and

communication among and within different neural circuits, thereby producing abnormal processing of sensory inputs necessary for normal social life. It is widely accepted that the innate properties of brain electrical activity produce pacemaker elements and linked networks that oscillate synchronously or asynchronously, likely reflecting a type of functional connectivity. Using phase coherence in multiple frequency EEG bands as a measure of functional connectivity, studies have shown evidence for both global hypoconnectivity and local hyperconnectivity in individuals with ASD. However, the nature of the brain's experience-dependent structural plasticity suggests that these abnormal patterns may be reversed with the proper type of treatment. Indeed, neurofeedback (NF) training, an intervention based on operant conditioning that results in self-regulation of brain electrical oscillations, has shown promise in addressing marked abnormalities in functional and structural connectivity. It is hypothesized that neurofeedback produces positive behavioral changes in ASD children by normalizing the aberrant connections within and between neural circuits. NF exploits the brain's plasticity to normalize aberrant connectivity patterns apparent in the autistic brain. By grounding this training in known anatomical (e.g., mirror neuron system) and functional markers (e.g., mu rhythms) of autism, NF training holds promise to support current treatments for this complex disorder. The proposed hypothesis specifically states that neurofeedback-induced alpha mu (8-12Hz) rhythm suppression or desynchronization, a marker of cortical activation, should induce neuroplastic changes and lead to normalization in relevant mirroring networks that have been associated with higher-order social cognition.

Pineda, J. A., Brang, D., Futagaki, C., Hecht, E., Grichanik, M., Wood, L., Bacon, M., & Carey, S. (2007). *Effects of neurofeedback training on action comprehension and imitation learning*. Chapter in Puckhaber, H. L. (Ed.), New research in biofeedback. Hauppauge, NY: Nova Science Publishers, pp. 133-152.

Pineda JA, Brang D, Hecht E, Edwards L, Carey S, Bacon M, Futagaki C, Suk D, Tom J, Birnbaum C, Rork A. (2008). Positive behavioral and electrophysiological changes following neurofeedback training in children with autism. *Research in Autism Spectrum Disorders* 2. 557-581. Two electrophysiological studies tested the hypothesis that operant conditioning of mu rhythms via neurofeedback training can renormalize mu suppression, an index of mirror neuron activity, and improve behavior in children diagnosed with autism spectrum disorders (ASD). In Study 1, eight high-functioning ASD participants were assigned to placebo or experimental groups before 10 weeks of training of the mu frequency band (8-13 Hz). Following training, experimental participants showed decreased mu power and coherence, increased sustained attention ability, and

improved scores on subscales of the ATEC compared to the placebo group. Both groups showed improvement in imitation ability. In Study 2, 19 high-functioning ASD children underwent a similar procedure with verified diagnoses, a modified double-blind protocol, and training of the high mu band (10-13 Hz). The results showed decreases in amplitude but increases in phase coherence in mu rhythms and normalization of mu rhythm suppression in experimental participants compared to placebo. Furthermore, like Study 1, participants showed improvements in sustained attention and in ATEC scores but no improvements in imitation following training. This suggests that training of the mu rhythm can be effective in producing changes in EEG and behavior in high-functioning ASD children, but does not affect imitation behavior *per se*.

Pop-Jordanova, N & Plasevska-Karanfilska, D. (2014). Autism - Genetics, electrophysiology and clinical syndromes. Prilozi;35(1). 133-46. (Full text is available at http://www.manu.edu.mk/prilozi). Autism is a severe and the most heritable developmental disorder, whose pathogenesis is still largely unknown. The rising incidence of autism in the last decade has increased the scientific interest and research. More than a thousand papers concerned with information about the etiology of this "static disorder of the immature brain" can be found on Pub Med. The aim of this paper is to give a review of published genetic chromosomal anomalies associated with autistic spectrum disorders, as well as to discuss common syndromes associated with autistic traits. In addition, some of our own findings in genetics, as well as in quantitative electroencephalography and neurofeedback training in autistic children, will be presented and discussed. Generally, the subsequent analyses indicate that the causes of autism include fewer common single-gene mutations and chromosomal abnormalities, as well as multiple interacting genes of weak effect. Genome-wide linkage analysis has identified several susceptibility loci and positional and functional candidate genes which appear to represent possible risks of the autistic spectrum. Electrophysiological findings showed high delta/theta activity in frontal-central regions, while in 25% high beta activity was detected as a result of anxiety. Neurofeedback is a promising therapy for symptom mitigation.

Scolnick, B. (2005). Effects of electroencephalogram biofeedback with Asperger's syndrome. ***International Journal of Rehabilitation Research*****, 28(2), 159-163.** This article reports the pilot study of electroencephalogram (EEG) biofeedback to improve focusing and decrease anxiety in 10 adolescent boys diagnosed with Asperger's syndrome attending a therapeutic day school. Five of the boys dropped out of the study before 12 sessions were completed. The analysis of pre- and post-intervention

quantitative EEGs for the five students who completed the study showed a trend to "normalization", but did not reach statistical significance. All five boys who completed 24 sessions showed improved behavior as rated by parents and teachers, but other factors, such as maturation could not be ruled out as causes of the improvement. The challenges facing this research and proposals for further exploration are outlined.

Sichel, A. G., Fehmi, L. G., & Goldstein, D. M. (1995). Positive outcome with neurofeedback treatment of a case of mild autism. *Journal of Neurotherapy*, 1(1), 60-64. This article looks at the experience of Frankie, an autistic 8 ½ year old boy. He was diagnosed as mildly autistic by several specialists. Our specialists claimed he was brain damaged and "autistic-like" and that there was no hope for improvement. At Frankie's mother's request, neurotherapy diagnosis and treatment was begun. Affter 31 sessions, Frankie showed positive changes in all the diagnostic dimensions defining autism in DSM-III-R. This has profound implications for treatment in a field with few low-risk alternatives.

Sokhadze, E., Singh, S., El-Baz, A., Baruth, J., Mathai, G., Sears, L., &Casanova M. (2009). Effect of a low-frequency repetitive transcranial magnetic stimulation (rTMS) on induced gamma frequency oscillations and event-related potentials during processing of illusory figures in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 39, 619-634. Previous studies by our group suggest that the neuropathology of autism is characterized by a disturbance of cortical modularity. In this model a decrease in the peripheral neuropil space of affected minicolumns provides for an inhibitory deficit and a readjustment in their signal to noise bias during information processing. In this study we proposed using low frequency transcranial magnetic stimulation (rTMS) as a way increasing the surround inhibition of minicolumns in autism. Thirteen patients (ADOS and ADI-R diagnosed) and equal number of controls participated in the study. Repetitive TMS was delivered at 0.5 Hz, 2 times per week for 3 weeks. Outcome measures based on event-related potentials (ERP), induced gamma activity, and behavioral measures showed significant post-TMS improvement. The results suggest that rTMS offers a potential therapeutic intervention for autism.

Sokhadze, E., Baruth, J., Tasman, A., Sears, L., Mathai, G., El-Baz, A., & Casanova, M. (2009). Event-related potential study of novelty processing abnormalities in autism. *Applied Psychophysiology & Biofeedback*, 34, 37-51. To better understand visual processing abnormalities in autism we studied the attention orienting related frontal event potentials (ERP) and the sustained attention related centro-parietal ERPs in a three stimulus oddball experiment. The three stimulus oddball paradigm was aimed to

test the hypothesis that individuals with autism abnormally orient their attention to novel distracters as compared to controls. A dense-array 128 channel EGI electroencephalographic (EEG) system was used on 11 high-functioning children and young adults with autism spectrum disorder (ASD) and 11 age-matched, typically developing control subjects. Patients with ASD showed slower reaction times but did not differ in response accuracy. At the anterior (frontal) topography the ASD group showed significantly higher amplitudes and longer latencies of early ERP components (e.g., P100, N100) to novel distracter stimuli in both hemispheres. The ASD group also showed prolonged latencies of late ERP components (e.g., P2a, N200, P3a) to novel distracter stimuli in both hemispheres. However, differences were more profound in the right hemisphere for both early and late ERP components. Our results indicate augmented and prolonged early frontal potentials and a delayed P3a component to novel stimuli, which suggest low selectivity in pre-processing and later-stage under-activation of integrative regions in the prefrontal cortices. Also, at the posterior (centro-parietal) topography the ASD group showed significantly prolonged N100 latencies and reduced amplitudes of the N2b component to target stimuli. In addition, the latency of the P3b component was prolonged to novel distracters in the ASD group. In general, the autistic group showed prolonged latencies to novel stimuli especially in the right hemisphere. These results suggest that individuals with autism over-process information needed for the successful differentiation of target and novel stimuli. We propose the potential application of ERP evaluations in a novelty task as outcome measurements in the biobehavioral treatment (e.g., EEG biofeedback, TMS) of autism.

Sokhadze, E., Sokhadze, G., & Casanova, M. (2012). Neuromodulation using transcranial DC Stimulation (tDCS) and repetitive Transcranial Magnetic Stimulation (rTMS) as a translational neuroscience approach to treat autism. *NeuroConnections*, 30, 16-18. Transcranial Direct Current Stimulation (tDCS) is a non-invasive neuromodulation procedure used to increase (anodal tDCS) or decrease (cathodal tDCS) cortical excitability. Recently, tDCS has been increasingly used to investigate cognitive functions in both healthy subjects and psychiatric patients. Our team was first to report positive effects of repetitive Transcranial Magnetic Stimulation (rTMS) in autism and provided rationale to consider it to be theory-driven neurotherapy. Although tDCS produces cortical effects over a longer period of time, it has several practical advantages over rTMS. First, tDCS is less prone to artifacts and is more suitable for controlled study designs. Second, tDCS is not as expensive as rTMS and can be performed with compact equipment. Third, tDCS can be administered while recording electroencephalogram (EEG) and autonomic nervous system activity, thus allowing for

concurrent investigation of physiological effects of neuromodulation. Fourth, tDCS may have great potential for cognitive and behavioral enhancement targeting to treat some of the core autism symptoms.

Sokhadze, E., Baruth, J., & Casanova, M. (2009). Neuropathological theories and EEG gamma oscillation abnormalities in autism. *NeuroConnections*, Fall, 34-37. To better understand visual processing abnormalities in autism we studied the attention orienting related frontal event potentials (ERP) and the sustained attention related centro-parietal ERPs in a three stimulus oddball experiment. The three stimulus oddball paradigm was aimed to test the hypothesis that individuals with autism abnormally orient their attention to novel distracters as compared to controls. A dense-array 128 channel EGI electroencephalographic (EEG) system was used on 11 high-functioning children and young adults with autism spectrum disorder (ASD) and 11 age-matched, typically developing control subjects. Patients with ASD showed slower reaction times but did not differ in response accuracy. At the anterior (frontal) topography the ASD group showed significantly higher amplitudes and longer latencies of early ERP components (e.g., P100, N100) to novel distracter stimuli in both hemispheres. The ASD group also showed prolonged latencies of late ERP components (e.g., P2a, N200, P3a) to novel distracter stimuli in both hemispheres. However, differences were more profound in the right hemisphere for both early and late ERP components. Our results indicate augmented and prolonged early frontal potentials and a delayed P3a component to novel stimuli, which suggest low selectivity in pre-processing and later-stage under-activation of integrative regions in the prefrontal cortices. Also, at the posterior (centro-parietal) topography the ASD group showed significantly prolonged N100 latencies and reduced amplitudes of the N2b component to target stimuli. In addition, the latency of the P3b component was prolonged to novel distracters in the ASD group. In general, the autistic group showed prolonged latencies to novel stimuli especially in the right hemisphere. These results suggest that individuals with autism over-process information needed for the successful differentiation of target and novel stimuli. We propose the potential application of ERP evaluations in a novelty task as outcome measurements in the biobehavioral treatment (e.g., EEG biofeedback, TMS) of autism.

Sokhadze, E., Baruth, J., Tasman, A., Mansoor, M., Ramaswamy, R., Sears, L., Mathai, G., El -Baz, A., & Casanova, M. F. (2010). Low-frequency repetitive transcranial magnetic stimulation (rTMS) affects event-related potential measures of novelty processing in autism. *Applied Psychophysiology & Biofeedback* 35(2), 147-161. In our previous study on individuals with autism spectrum disorder (ASD)

(Sokhadze et al., Appl Psychophysiol Biofeedback 34:37-51, 2009a) we reported abnormalities in the attention-orienting frontal event-related potentials (ERP) and the sustained-attention centro-parietal ERPs in a visual oddball experiment. These results suggest that individuals with autism over-process information needed for the successful differentiation of target and novel stimuli. In the present study we examine the effects of low-frequency, repetitive Transcranial Magnetic Stimulation (rTMS) on novelty processing as well as behavior and social functioning in 13 individuals with ASD. Our hypothesis was that low-frequency rTMS application to dorsolateral prefrontal cortex (DLFPC) would result in an alteration of the cortical excitatory/inhibitory balance through the activation of inhibitory GABAergic double bouquet interneurons. We expected to find post-TMS differences in amplitude and latency of early and late ERP components. The results of our current study validate the use of low-frequency rTMS as a modulatory tool that altered the disrupted ratio of cortical excitation to inhibition in autism. After rTMS the parieto-occipital P50 amplitude decreased to novel distracters but not to targets; also the amplitude and latency to targets increased for the frontal P50 while decreasing to non-target stimuli. Low-frequency rTMS minimized early cortical responses to irrelevant stimuli and increased responses to relevant stimuli. Improved selectivity in early cortical responses lead to better stimulus differentiation at later-stage responses as was made evident by our P3b and P3a component findings. These results indicate a significant change in early, middle-latency and late ERP components at the frontal, centro-parietal, and parieto-occipital regions of interest in response to target and distracter stimuli as a result of rTMS treatment. Overall, our preliminary results show that rTMS may prove to be an important research tool or treatment modality in addressing the stimulus hypersensitivity characteristic of autism spectrum disorders.

Sokhadze, E., Baruth, J., El-Baz, A., Horrell, T., Sokhadze, G., Carroll, T., Tasman, A., Sears, L. & Casanova, M. (2010). Impaired error monitoring and correction function in autism. *Journal of Neurotherapy*,14, 79-95. One important executive function known to be compromised in autism spectrum disorder (ASD) is related to response error monitoring and post-error response correction. Several reports indicate that children with ASD show reduced error processing and deficient behavioral correction after an error is committed. Error sensitivity can be readily examined by measuring event-related potentials (ERP) associated with responses to errors, the fronto-central error-related negativity (ERN), and the error-related positivity (Pe). The goal of our study was to investigate whether reaction time (RT), error rate, post-error RT change, ERN, and Pe will show positive changes following 12-week long slow frequency repetitive TMS (rTMS) over dorsolateral prefrontal cortex (DLPFC) in high functioning children with ASD. We

hypothesized that 12 sessions of 1 Hz rTMS bilaterally applied over the DLPFC will result in improvements reflected in both behavioral and ERP measures. Participants were randomly assigned to either active rTMS treatment or wait-list (WTL) groups. Baseline and post-TMS/or WTL EEG was collected using 128 channel EEG system. The task involved the recognition of a specific illusory shape, in this case a square or triangle, created by three or four inducer disks. ERN in TMS treatment group became significantly more negative. The number of omission errors decreased post-TMS. The RT did not change, but post-error RT became slower. There were no changes in RT, error rate, post-error RT slowing, nor in ERN/Pe measures in the wait-list group. Our results show significant post-TMS differences in the response-locked ERP such as ERN, as well as behavioral response monitoring measures indicative of improved error monitoring and correction function. The ERN and Pe, along with behavioral performance measures, can be used as functional outcome measures to assess the effectiveness of neuromodulation (e.g., rTMS) in children with autism and thus may have important practical implications.

Sokhadze, E., Baruth, J. M., Sears, L., Sokhadze, GE., El-Baz, A. S., & Casanova, MF. (2012). Prefrontal neuromodulation using rTMS improves error monitoring and correction functions in autism. ***Applied Psychophysiology & Biofeedback*****, 37(2), 91-102.** One important executive function known to be compromised in autism spectrum disorder (ASD) is related to response error monitoring and post-error response correction. Several reports indicate that children with ASD show reduced error processing and deficient behavioral correction after an error is committed. Error sensitivity can be readily examined by measuring event-related potentials (ERP) associated with responses to errors, the fronto-central error-related negativity (ERN), and the error-related positivity (Pe). The goal of our study was to investigate whether reaction time (RT), error rate, post-error RT change, ERN, and Pe will show positive changes following 12-week long slow frequency repetitive TMS (rTMS) over dorsolateral prefrontal cortex (DLPFC) in high functioning children with ASD. We hypothesized that 12 sessions of 1 Hz rTMS bilaterally applied over the DLPFC will result in improvements reflected in both behavioral and ERP measures. Participants were randomly assigned to either active rTMS treatment or wait-list (WTL) groups. Baseline and post-TMS/or WTL EEG was collected using 128 channel EEG system. The task involved the recognition of a specific illusory shape, in this case a square or triangle, created by three or four inducer disks. ERN in TMS treatment group became significantly more negative. The number of omission errors decreased post-TMS. The RT did not change, but post-error RT became slower. There were no changes in RT, error

rate, post-error RT slowing, nor in ERN/Pe measures in the wait-list group. Our results show significant post-TMS differences in the response-locked ERP such as ERN, as well as behavioral response monitoring measures indicative of improved error monitoring and correction function. The ERN and Pe, along with behavioral performance measures, can be used as functional outcome measures to assess the effectiveness of neuromodulation (e.g., rTMS) in children with autism and thus may have important practical implications.

Sokhadze, E., Baruth, J., Sears, L., Sokhadze, GE., El-Baz, A., Williams, E., Klapheke, R., & Casanova, MF. (2012). Event related potentials study of attention regulation during illusory figure categorization task in ADHD, autism spectrum disorders, and typical children. ***Journal of Neurotherapy*****,16, 12-31.** Autism spectrum disorders (ASD) and attention deficit/hyperactivity disorder (ADHD) are very common developmental disorder that share some similar symptoms of social, emotional, and attentional deficits. This study is aimed to help understand the differences and similarities of these deficits using analysis of dense-array event-related potentials (ERP) during an illusory figure recognition task. Although ADHD and ASD seem very distinct, they have been shown to share some similarities in their symptoms. Our hypothesis was that children with ASD will show less pronounced differences in ERP responses to target and nontarget stimuli as compared to typical children and, to a lesser extent, ADHD. Participants were children with ASD (N=16), ADHD (N=16), and controls (N=16). EEG was collected using a 128-channel EEG system. The task involved the recognition of a specific illusory shape, in this case a square or triangle, created by three or four inducer disks. There were no between-group differences in reaction time (RT) to target stimuli, but both ASD and ADHD committed more errors; specifically, the ASD group had statistically higher commission error rate than controls. Posterior RT in ASD group was exhibited in a posterror speeding rather than corrective RT slowing typical for the controls. The ASD group also demonstrated an attenuated error-related negativity as compared to ADHD and controls. The fronto-central P200, N200, and P300 were enhanced and less differentiated in response to target and nontarget figures in the ASD group. The same ERP components were marked by more prolonged latencies in the ADHD group as compared to both ASD and typical controls. The findings are interpreted according to the "minicolumnar" hypothesis proposing existence of neuropathological differences in ASD and ADHD, specifically minicolumnar number/width morphometry spectrum differences. In autism, a model of local hyperconnectivity and long-range hypoconnectivity explains many of the behavioral and cognitive deficits present in the condition, whereas the inverse arrangement of local hypoconnectivity and

long-range hyperconnectivity in ADHD explains some deficits typical for this disorder. The current ERP study supports the proposed suggestion that some between-group differences could be manifested in the frontal ERP indices of executive functions during performance on an illusory figure categorization task.

Sokhadze, E., Sokhadze, G., & Casanova, M. (2012). Neuromodulation using transcranial DC Stimulation (tDCS) and repetitive Transcranial Magnetic Stimulation (rTMS) as a translational neuroscience approach to treat autism. NeuroConnections, 30, 16-18.

Steiner, NJ., Frenette, E., Hynes, C., Pisarik, E., Tomasetti, K., Perrin, EC. & Rene, K. (2014). A pilot feasibility study of neurofeedback for children with autism. Applied Psychophysiology and Biobeedback:39(2). 99-107. Neurofeedback (NFB) is an emerging treatment for children with autism spectrum disorder (ASD). This pilot study examined the feasibility of NFB for children with ASD. Ten children ages 7-12 with high functioning ASD and attention difficulties received a NFB attention training intervention. A standardized checklist captured feasibility, including focus during exercises and academic tasks, as well as off-task behaviors. Active behaviors and vocalizations were the most frequent off-task behaviors. Positive reinforcement and breaks including calm breathing exercises were the most common supports. Low motivation was associated with higher feasibility challenges, yet parental involvement and accommodations were helpful. This pilot study shows that it is feasible to conduct NFB sessions with children with high functioning autism and attention difficulties.

Thompson L, Thompson M, Reid A. (2010). Functional neuroanatomy and the rationale for using EEG biofeedback for clients with Asperger's syndrome. *Appl Psychophysiol Biofeedback*. 2010 Mar;35(1):39-6. This paper reviews the symptoms of Asperger's Syndrome (AS), a disorder along the autism continuum, and highlights research findings with an emphasis on brain differences. Existing theories concerning AS are described, including theory of mind (Hill and Frith in Phil Trans Royal Soc Lond, Bull 358:281-289, 2003), mirror neuron system (Ramachandran and Oberman in Sci Am 295(5):62-69, 2006), and Porges' (Ann N Y Acad Sci 1008:31-47, 2003, The neurobiology of autism, Johns Hopkins University Press, Baltimore, 2004) polyvagal theory. (A second paper, Outcomes using EEG Biofeedback Training in Clients with Asperger's Syndrome, summarizes clinical outcomes obtained with more than 150 clients.) Patterns seen with QEEG assessment are then presented. Single channel assessment at the vertex (CZ) reveals patterns similar to those found in Attention-Deficit/Hyperactivity Disorder. Using 19-channel data, significant differences (z-scores >

2) were found in the amplitude of both slow waves (excess theta and/or alpha) and fast waves (beta) at various locations. Differences from the norm were most often found in mirror neuron areas (frontal, temporal and temporal-parietal). There were also differences in coherence patterns, as compared to a normative database (Neuroguide). Low Resolution Electromagnetic Tomography Analysis (Pascual-Marqui et al. in Methods Find Exp Clin Pharmacol 24C:91-95, 2002) suggested the source of the abnormal activity was most often the anterior cingulate. Other areas involved included the amygdala, uncus, insula, hippocampal gyrus, parahippocampal gyrus, fusiform gyrus, and the orbito-frontal and/or ventromedial areas of the prefrontal cortex. Correspondence between symptoms and the functions of the areas found to have abnormalities is evident and those observations are used to develop a rationale for using EEG biofeedback, called neurofeedback (NFB), intervention. NFB training is targeted to improve symptoms that include difficulty reading and mirroring emotions, poor attention to the outside world, poor self-regulation skills, and anxiety. Porges' polyvagal theory is used to emphasize the need to integrate NFB with biofeedback (BFB), particularly heart rate variability training. We term this emerging understanding the Systems Theory of Neural Synergy. The name underscores the fact that NFB and BFB influence dynamic circuits and emphasizes that, no matter where we enter the nervous system with an intervention, it will seek its own new balance and equilibrium.

Thompson, L., Thompson, M., Reid, A. (2010). Neurofeedback outcomes with clients with Asperger's syndrome. ***Applied Psychophysiology and Biofeedback*****, 35(1) 63-81.** This paper summarizes data from a review of neurofeedback (NFB) training with 150 clients with Asperger's Syndrome (AS) and 9 clients with Autistic Spectrum Disorder (ASD) seen over a 15 year period (1993-2008) in a clinical setting. The main objective was to investigate whether electroncephalographic (EEG) biofeedback, also called neurofeedback (NFB), made a significant difference in clients diagnosed with AS. An earlier paper (Thompson et al. 2009) reviews the symptoms of AS, highlights research findings and theories concerning this disorder, discusses QEEG patterns in AS (both single and 19-channel), and details a hypothesis, based on functional neuroanatomy, concerning how NFB, often paired with biofeedback (BFB), might produce a change in symptoms. A further aim of the current report is to provide practitioners with a detailed description of the method used to address some of the key symptoms of AS in order to encourage further research and clinical work to refine the use of NFB plus BFB in the treatment of AS. All charts were included for review where there was a diagnosis of AS or ASD and pre- and post-training testing results were available for one or more of the standardized tests used. Clients received 40-60 sessions of NFB, which was combined with training in metacognitive strategies and, for most older adolescent and adult clients,

with BFB of respiration, electrodermal response, and, more recently, heart rate variability. For the majority of clients, feedback was contingent on decreasing slow wave activity (usually 3-7 Hz), decreasing beta spindling if it was present (usually between 23 and 35 Hz), and increasing fast wave activity termed sensorimotor rhythm (SMR) (12-15 or 13-15 Hz depending on assessment findings). The most common initial montage was referential placement at the vertex (CZ) for children and at FCz (midway between FZ and CZ) for adults, referenced to the right ear. Metacognitive strategies relevant to social understanding, spatial reasoning, reading comprehension, and math were taught when the feedback indicated that the client was relaxed, calm, and focused. Significant improvements were found on measures of attention (T.O.V.A. and IVA), core symptoms (Australian Scale for Asperger's Syndrome, Conners' Global Index, SNAP version of the DSM-IV criteria for ADHD, and the ADD-Q), achievement (Wide Range Achievement Test), and intelligence (Wechsler Intelligence Scales). The average gain for the Full Scale IQ score was 9 points. A decrease in relevant EEG ratios was also observed. The ratios measured were $(4\text{-}8\ Hz)^2/(13\text{-}21\ Hz)^2$, (4-8 Hz)/(16-20 Hz), and (3-7 Hz)/(12-15 Hz). The positive outcomes of decreased symptoms of Asperger's and ADHD (including a decrease in difficulties with attention, anxiety, aprosodias, and social functioning) plus improved academic and intellectual functioning, provide preliminary support for the use of neurofeedback as a helpful component of effective intervention in people with AS.

Vasa, RA., Carroll, LM., Nozzolillio, AA., Mahajan, R., Mazurek, MO., Bennett, AE., Wink, LK. & Bernal, MP. (2014). A systematic review of treatments for anxiety in youth with autism spectrum disorders. J Autism Dev Disord. July 2014 Early e-pub. This study systematically examined the efficacy and safety of psychopharmacological and non-psychopharmacological treatments for anxiety in youth with autism spectrum disorders (ASD). Four psychopharmacological, nine cognitive behavioral therapy (CBT), and two alternative treatment studies met inclusion criteria. Psychopharmacological studies were descriptive or open label, sometimes did not specify the anxiety phenotype, and reported behavioral activation. Citalopram and buspirone yielded some improvement, whereas fluvoxamine did not. Non-psychopharmacological studies were mainly randomized controlled trials (RCTs) with CBT demonstrating moderate efficacy for anxiety disorders in youth with high functioning ASD. Deep pressure and neurofeedback provided some benefit. All studies were short-term and included small sample sizes. Large scale and long term RCTs examining psychopharmacological and non-psychopharmacological treatments are sorely needed

COGNITIVE, SPORT AND CORPORATE OPTIMAL AND PEAK PERFORMANCE

Angelakis, E., Stathopoulou, S., Frymiare, J. L., Green, D. L., Lubar, J. F., & Kounios, J. (2007). EEG neurofeedback: A brief overview and an example of peak alpha frequency training for cognitive enhancement in the elderly. ***Clinical Neuropsychology*****, 21(1), 110-129.** OBJECTIVE: Electroencephalographic (EEG) peak alpha frequency (PAF) (measured in Hz) has been correlated to cognitive performance between healthy and clinical individuals, and among healthy individuals. PAF also varies within individuals across developmental stages, among different cognitive tasks, and among physiological states induced by administration of various substances. The present study suggests that, among other things, PAF reflects a trait or state of cognitive preparedness. METHODS: Experiment 1 involved 19-channel EEG recordings from 10 individuals with traumatic brain injury (TBI) and 12 healthy matched controls, before, during, and after tasks of visual and auditory attention. Experiment 2 involved EEG recordings from 19 healthy young adults before and after a working memory task (WAIS-R Digit Span), repeated on 2 different days to measure within-individual differences. RESULTS: Experiment 1 showed significantly lower PAF in individuals with TBI, mostly during post-task rest. Experiment 2 showed PAF during pre-task baseline to be significantly correlated with Digit Span performance of the same day but not with Digit Span performance of another day. Moreover, PAF was significantly increased after Digit Span for those participants whose PAF was lower than the sample median before the task, but not for those who had it higher. Finally, both PAF and Digit Span performance were increased during the second day. CONCLUSIONS: PAF was shown to detect both trait and state differences in cognitive preparedness, as well as to be affected by cognitive tasks. Traits are better reflected during post-task rest, whereas states are better reflected during initial resting baseline recordings.

Bertollo, M., Bortoli, L., Gramaccione, G., Hanin, Y., Comani, S. & Robazza, C. (2013). Behavioral and psychophiological correlates of athletic performance: A test of the multi-action plan model. Applkied Psychophysiology and Biofeedback: 38(2). 91-99. The main purposes of the present study were to substantiate the existence of the four types of performance categories (i.e., optimal-automatic, optimal-controlled, suboptimal-controlled, and suboptimal-automatic) as hypothesised in the multi-action plan (MAP) model, and to investigate whether some specific affective, behavioural,

psychophysiological, and postural trends may typify each type of performance. A 20-year-old athlete of the Italian shooting team, and a 46-year-old athlete of the Italian dart-throwing team participated in the study. Athletes were asked to identify the core components of the action and then to execute a large number of shots/flights. A 2 × 2 (optimal/suboptimal × automated/controlled) within subjects multivariate analysis of variance was performed to test the differences among the four types of performance. Findings provided preliminary evidence of psychophysiological and postural differences among four performance categories as conceptualized within the MAP model. Monitoring the entire spectrum of psychophysiological and behavioural features related to the different types of performance is important to develop and implement biofeedback and neurofeedback techniques aimed at helping athletes to identify individual zones of optimal functioning and to enhance their performance.

Boynton, T. (2001). Applied research using alpha/theta training for enhancing creativity and well-being. ***Journal of Neurotherapy,*** **5(1-2), 5-18.** Introduction. Previous research has supported anecdotal reports of a possible correlation between the state of hypnagogia and the enhancement of creative ability (Green, 1972; Green, Green, & Walters, 1970, 1974; Parks, 1996; Stembridge, 1972; Whisenant & Murphy, 1977). Some psychologists (e.g., Maslow, 1963; Rogers, 1978) have suggested that there is also a correlation between creative ability and enhanced well-being. Methods. This study utilized an 8-week repeated-measures experimental design to investigate the effects of electroencephalogram (EEG) biofeedback on the willful use of hypnagogia for increasing creativity and well-being. The sample size of 62 (30 experimental subjects and 32 controls) was comprised of both sexes with a mean age of 45. The EEG parameters of hypnagogia were broadly defined as the presence and pre-dominance of alpha and theta brain wave activity. Creativity was defined by the three most readily agreed upon divergent thinking abilities: (a) fluency (the ability to generate numerous ideas), (b) flexibility (the ability to see a given problem from multiple perspectives), and (c) originality (the ability to come up with new and unique ideas). Results. Hypnagogia was analyzed through multiple univariate analyses of variance. The EEG data showed that both experimental and control participants were able to achieve light to deep hypnagogic states in every training session. T-tests results on fluency and originality scores from the Torrance Test of Creative Thinking and the Christensen-Guilford Associational Fluency Test showed no significant changes in pre- and post-tests for either group. However, flexibility in thinking, as measured by the Alternate Uses Test was significantly increased ($p < .001$) for all participants. Well-being, as measured by the Friedman Well-Being Scale, also significantly increased for all participants ($p = .002$). Discussion. The data suggest that willful use of hynagogia may indeed increase creativity and well-being.

Participants reported increased personal creativity, stress reduction, heightened self-awareness, emotional equanimity, and improved work performance.

Budzynski, T., Budzynski, H. K., &I Tang, H-Y. (2007). *Brain brightening: restoring the aging mind*. Chapter in J. R. Evans (Ed.), Handbook of Neurofeedback. Binghamton, NY: Haworth Medical Press, pp. 231-265.

Budzynski, T. H. (1996). Brain brightening: Can neurofeedback improve cognitive process? *Biofeedback*, 24(2), 14-17. (abstract to follow)

Cannon R, Lubar J, Congedo M, Thornton K, Towler K, Hutchens T. (2007). The effects of neurofeedback training in the cognitive division of the anterior cingulate gyrus. *Int J Neurosci*;117(3):337-57. This study examines the efficacy of neurofeedback training in the cognitive division of the anterior cingulate gyrus and describes its relationship with cortical regions known to be involved in executive functions. This study was conducted with eight non-clinical students, four male and four female, with a mean age of twenty-two. Learning occurred in the ACcd at significant levels over sessions and in the anterior regions that receive projections from the AC. There appears to be a multidimensional executive circuit that increases in the same frequency in apparent synchrony with the AC and it may be possible to train this sub-cortical region using LNFB.

Dekker, MK., Van den Berg, BR., Denissen, AJ., Sitskoom, MM. & Van Boxtel, GJ. (2014). Feasibility of eyes open alpha power training for mental enhancement in elite gymnasts. J Sports Sci: Aug32(16). 1550-1560. Abstract This study focuses on a novel, easy to use and instruction-less method for mental training in athletes. Previous findings suggest that particular mental capacities are needed for achieving peak performance; including attentional control, focus, relaxation and positive affect. Electroencephalography (EEG) alpha brain activity has been associated with neural inhibition during processes of selective attention, for improving efficiency in information processing. Here we hypothesised that eyes open alpha power training by music teaches athletes to (1) learn to self-regulate their brain activity, and (2) learn to increase their baseline alpha power, herewith improving mental capacities such as focusing the allocation of attention. The study was double-blind and placebo-controlled. Twelve elite gymnasts were either given eyes open alpha power training or random beta power training (controls). Results indicate small improvements in sleep quality, mental and physical shape. In our first attempt at getting a grip on mental capacities in athletes, we think this novel training method can be promising. Because gymnastics is one of the most mentally demanding

sports, we value even small benefits for the athlete and consider them indicative for future research.

Egner, T., & Gruzelier, J. H. (2004). EEG biofeedback of low beta band components: Frequency-specific effects on variables of attention and event-related brain potentials. ***Clinical Neurophysiology*****, 115, 131-139.** Objective: To test a common assumption underlying the clinical use of electroencephalographic (EEG) biofeedback training (neurofeedback), that the modulation of discreet frequency bands is associated with frequency-specific effects. Specifically, the proposal was assessed that enhancement of the low beta components sensorimotor rhythm (SMR: 1215 Hz) and beta1 (1518 Hz) affect different aspects of attentional processing. Methods: Subjects (n=25) were randomly allocated to training with either an SMR or beta1 protocol, or to a non-neurofeedback control group. Subjects were assessed prior and subsequent to the training process on two tests of sustained attention. The neurofeedback participants were also assessed on target P300 event-related potential (ERP) amplitudes in a traditional auditory oddball paradigm. Results: Protocol-specific effects were obtained in that SMR training was associated with increased perceptual sensitivity d prime (d), and reduced omission errors and reaction time variability. Beta1 training was associated with faster reaction times and increased target P300 amplitudes, whereas no changes were evident in the control group. Conclusions: Neurofeedback training of SMR and beta1 band components led to significant and protocol-specific effects in healthy subjects. The data can be interpreted as indicating a general attention-enhancing effect of SMR training, and an arousal-enhancing effect of beta1 training.

Egner, T., & Gruzelier, J. H. (2004). The temporal dynamics of electroencephalographic responses to alpha/theta neurofeedback training in healthy subjects. ***Journal of Neurotherapy,*** **8(1), 43-57.** Background. It has been shown recently that accurate feedback of alpha and theta electroencephalographic (EEG) activity, as employed in the commonly used “alpha/theta protocol,” induced linear increments in within-session theta-over-alpha ratios in comparison to non-contingent feedback in a healthy sample. These data verify that alpha/theta feedback can facilitate within-session operant control over the EEG signature targeted by the training protocol. However, it is neither known whether any between-session theta/alpha ratio changes do reliably occur, nor what kind of temporal dynamics between the alpha and theta band amplitudes characterize within-session and/or between-session theta/alpha ratio changes. Method. In order to address these issues, analyses of an extensive data set (n = 48) of alpha/theta training in healthy volunteers were carried out. Specifically, alpha, theta, and theta/alpha ratio EEG dynamics were contrasted between groups of subjects that engaged in 10

sessions of training at PZ (n = 28), five sessions of training at PZ (n = 10), and 10 sessions at FZ (n = 10). Results. For alpha/theta training at PZ, significant within-session increments in theta/alpha ratios were mediated by slightly less pronounced decrements in theta than in alpha activity during the sessions. The traditional alpha/theta protocol at PZ was nevertheless associated with significant theta activity increments across the training process. For training at FZ, no significant within- or between-session changes in theta, alpha, or theta/alpha ratio values were found, but a progressively higher rate of within-session theta/alpha ratio modulation was evident across sessions. Furthermore, in contrast to the PZ groups, any changes in theta/alpha ratio at FZ were mediated by increases in theta relative to alpha amplitudes. Conclusions. These data elucidate the dynamics underlying the within-session theta/alpha ratio increments associated with posterior alpha/theta training, and document an increase in theta activity across 10 sessions of training, offering further evidence for a neurophysiological impact of this training protocol. In addition, the contrasting EEG characteristics associated with frontal versus posterior alpha/theta training underline the heterogeneous nature of these frequency components across varying scalp sites.

Egner, T. & Gruzelier, JH. (2003). Ecological validity of neurofeedback: modulation of slow wave EEG enhances musical performance. *NeuroReport*, 14(9) 1221-1224. Biofeedback-assisted modulation of electrocortical activity has been established to have intrinsic clinical benefits and has been shown to improve cognitive performance in healthy humans. In order to further investigate the pedagogic relevance of electroencephalograph (EEG) biofeedback (neurofeedback) for enhancing normal function, a series of investigations assessed the training's impact on an ecologically valid real-life behavioural performance measure: music performance under stressful conditions in conservatoire students. In a pilot study, single-blind expert ratings documented improvements in musical performance in a student group that received training on attention and relaxation related neurofeedback protocols, and improvements were highly correlated with learning to progressively raise theta (5-8 Hz) over alpha (8-11 Hz) band amplitudes. These findings were replicated in a second experiment where an alpha/theta training group displayed significant performance enhancement not found with other neurofeedback training protocols or in alternative interventions, including the widely applied Alexander technique.

Gruzelier, JH. (2014). EEG-neurofeedback for optimizing performance. III: A review of methodological and theoretical considerations. Neurosci Biobehav Rev: Jul:44. 159-182. In continuing this three-part review on validation of EEG-neurofeedback for optimal performance evidence is first provided for feedback influences on the CNS, the

integration of EEG with fMRI methodology as well as anatomical correlates. Then whereas Parts I and II reviewed the considerable behavioural outcome gains and evidence for their feedback causation, part III lays bare the not inconsiderable methodological and theoretical conundrums. Cardinal assumptions amongst practitioners about specificity of topography, behavioural outcome and frequency bands are critically examined. The hitherto mostly neglected nature of feedback learning is reviewed including evidence of within- and between-session and successive baseline learning; the enduring impact on the tonic EEG; implications for experimental design, individual differences and the trainer-participant interface; distinguishing between the learning and mastery of self-regulation; connectivity, ratio, unidirectional and multimodal feedback protocols. A thorough grounding in human neuroscience plus interpersonal skills are considered prerequisites for scientific advancement and ethically sound practice.

Gruzelier, JH. (2014). EEG-neurofeedback for optimizing performance. II: Creativity, the performing arts and ecological validity. Neurosci Biobehav Rev: Jul:44. 142-158. As a continuation of a review of evidence of the validity of cognitive/affective gains following neurofeedback in healthy participants, including correlations in support of the gains being mediated by feedback learning (Gruzelier, 2014a), the focus here is on the impact on creativity, especially in the performing arts including music, dance and acting. The majority of research involves alpha/theta (A/T), sensory-motor rhythm (SMR) and heart rate variability (HRV) protocols. There is evidence of reliable benefits from A/T training with advanced musicians especially for creative performance, and reliable benefits from both A/T and SMR training for novice music performance in adults and in a school study with children with impact on creativity, communication/presentation and technique. Making the SMR ratio training context ecologically relevant for actors enhanced creativity in stage performance, with added benefits from the more immersive training context. A/T and HRV training have benefitted dancers. The neurofeedback evidence adds to the rapidly accumulating validation of neurofeedback, while performing arts studies offer an opportunity for ecological validity in creativity research for both creative process and product.

Gruzelier, JH. (2014). EEG-neurofeedback for optimizing performance. I: A review of cognitive and affective outcome in healthy participants. Neurosci Biobehav Rev: Jul:44. 124-141. A re-emergence of research on EEG-neurofeedback followed controlled evidence of clinical benefits and validation of cognitive/affective gains in healthy participants including correlations in support of feedback learning mediating outcome. Controlled studies with healthy and elderly participants, which have increased exponentially, are reviewed including protocols from the clinic: sensory-motor rhythm,

beta1 and alpha/theta ratios, down-training theta maxima, and from neuroscience: upper-alpha, theta, gamma, alpha desynchronisation. Outcome gains include sustained attention, orienting and executive attention, the P300b, memory, spatial rotation, RT, complex psychomotor skills, implicit procedural memory, recognition memory, perceptual binding, intelligence, mood and well-being. Twenty-three of the controlled studies report neurofeedback learning indices along with beneficial outcomes, of which eight report correlations in support of a meditation link, results which will be supplemented by further creativity and the performing arts evidence in Part II. Validity evidence from optimal performance studies represents an advance for the neurofeedback field demonstrating that cross fertilisation between clinical and optimal performance domains will be fruitful. Theoretical and methodological issues are outlined further in Part III.

Gruzelier, JH, Foks, M, Steffert, T, Chen, MJ. & Ros, T. (2013). Beneficial outcome from EEG-neurofeedback on creative music performance, attention and well-being in school children. *Biol Psychol*. 2013 Apr 25. pii: S0301-0511(13)00099-9. doi: 10.1016/j.biopsycho.2013.04.005. [Epub ahead of print]. We earlier reported benefits for creativity in rehearsed music performance from alpha/theta (A/T) neurofeedback in conservatoire studies (Egner & Gruzelier, 2003) which were not found with SMR, Beta1, mental skills, aerobics or Alexander training, or in standby controls. Here the focus was the impact on novice music performance. A/T and SMR training were compared in 11-year old school children along with non-intervention controls with outcome measures not only of rehearsed music performance but also of creative improvisation, as well as sustained attention and phenomenology. Evidence of effective learning in the school setting was obtained for A/T and SMR/beta2 ratios. Preferential benefits from A/T for rehearsed music performance were replicated in children for technique and communication ratings. Benefits extended to creativity and communication ratings for creative improvisation which were shared with SMR training, disclosing an influence of SMR on unrehearsed music performance at a novice level with its greater cognitive demands. In a first application of A/T for improving sustained attention (TOVA), it was found to be more successful than SMR training, with a notable reduction in commission errors in the children, 15/33 of whom had attention indices in the ADHD range. Phenomenological reports were in favour of neurofeedback and well-being benefits. Implementing neurofeedback in the daily school setting proved feasible and holds pedagogic promise.

Gruzelier JH., Thompson T., Redding E., Brandt R & Steffert T. (2013). Application of alpha/theta neurofeedback and heart rate variability training to young contemporary dancers: State anxiety and creativity. Int J Psychophysiol. 2013 May 15. doi:

10.1016/j.ijpsycho.2013.05.004. As one in a series on the impact of EEG-neurofeedback in the performing arts, we set out to replicate a previous dance study in which alpha/theta (A/T) neurofeedback and heart rate variability (HRV) biofeedback enhanced performance in competitive ballroom dancers compared with controls. First year contemporary dance conservatoire students were randomized to the same two psychophysiological interventions or a choreology instruction comparison group or a no-training control group. While there was demonstrable neurofeedback learning, there was no impact of the three interventions on dance performance as assessed by four experts. However, HRV training reduced anxiety and the reduction correlated with improved technique and artistry in performance; the anxiety scale items focused on autonomic functions, especially cardiovascular activity. In line with the putative impact of hypnogogic training on creativity A/T training increased cognitive creativity with the test of unusual uses, but not insight problems. Methodological and theoretical implications are considered.

Gruzelier, J. (2009). A theory of alpha/theta neurofeedback, creative performance enhancement, long distance functional connectivity and psychological integration. *Cognitive Processing*, 10 (Suppl 1), S101-109. Professionally significant enhancement of music and dance performance and mood has followed training with an EEG-neurofeedback protocol which increases the ratio of theta to alpha waves using auditory feedback with eyes closed. While originally the protocol was designed to induce hypnogogia, a state historically associated with creativity, the outcome was psychological integration, while subsequent applications focusing on raising the theta-alpha ratio, reduced depression and anxiety in alcoholism and resolved post traumatic stress syndrome (PTSD). In optimal performance studies we confirmed associations with creativity in musical performance, but effects also included technique and communication. We extended efficacy to dance and social anxiety. Diversity of outcome has a counterpart in wide ranging associations between theta oscillations and behaviour in cognitive and affective neuroscience: in animals with sensory-motor activity in exploration, effort, working memory, learning, retention and REM sleep; in man with meditative concentration, reduced anxiety and sympathetic autonomic activation, as well as task demands in virtual spatial navigation, focussed and sustained attention, working and recognition memory, and having implications for synaptic plasticity and long term potentiation. Neuroanatomical circuitry involves the ascending mescencephalic-cortical arousal system, and limbic circuits subserving cognitive as well as affective/motivational functions. Working memory and meditative bliss, representing cognitive and affective domains, respectively, involve coupling between frontal and posterior cortices, exemplify a role for theta and alpha waves in mediating the interaction between distal and widely

distributed connections. It is posited that this mediation in part underpins the integrational attributes of alpha-theta training in optimal performance and psychotherapy, creative associations in hypnogogia, and enhancement of technical, communication and artistic domains of performance in the arts.

Hannah ST, Balthazard PA, Waldman DA, Jennings PL & Thatcher RW. (2103). The psychological and neurological bases of leader self-complexity and effects on adaptive decision-making. J Appl Psychol. 2013 May;98(3):393-411. doi: 10.1037/a0032257. Epub 2013 Apr 1. Complex contexts and environments require leaders to be highly adaptive and to adjust their behavioral responses to meet diverse role demands. Such adaptability may be contingent upon leaders having requisite complexity to facilitate effectiveness across a range of roles. However, there exists little empirical understanding of the etiology or basis of leader complexity. To this end, we conceptualized a model of leader self-complexity that is inclusive of both the mind (the complexity of leaders' self-concepts) and the brain (the neuroscientific basis for complex leadership). We derived psychometric and neurologically based measures, the latter based on quantitative electroencephalogram (qEEG) profiles of leader self-complexity, and tested their separate effects on the adaptive decision-making of 103 military leaders. Results demonstrated that both measures accounted for unique variance in external ratings of adaptive decision-making. We discuss how these findings provide a deeper understanding of the latent and dynamic mechanisms that underpin leaders' self-complexity and their adaptability. (PsycINFO Database Record (c) 2013 APA, all rights reserved).

Hanslmayer, S., Sauseng, P., Doppelmayr, M., Schabus, M., & Klimesch, W. (2005). Increasing individual upper alpha by neurofeedback improves cognitive performance in human subjects. ***Applied Psychophysiology & Biofeedback*****, 30(1), 1-10.** The hypothesis was tested of whether neurofeedback training (NFT)—applied in order to increase upper alpha but decrease theta power—is capable of increasing cognitive performance. A mental rotation task was performed before and after upper alpha and theta NFT. Only those subjects who were able to increase their upper alpha power (responders) performed better on mental rotations after NFT. Training success (extent of NFT-induced increase in upper alpha power) was positively correlated with the improvement in cognitive performance. Furthermore, the EEG of NFT responders showed a significant increase in reference upper alpha power (i.e. in a time interval preceding mental rotation). This is in line with studies showing that increased upper alpha power in a prestimulus (reference) interval is related to good cognitive performance.

Hatfield, B, Haufler, A. (2009). Brain processes and neurofeedback for performance enhancement of precision motor behavior. *NeuroImage,* 5638 810-817. Based on a number of empirical investigations of cerebral cortical dynamics during precision aiming tasks (i.e. marksmanship) employing electroencephalography (EEG) refinement of cortical activity and attenuation of nonessential cortico-cortical communication with the motor planning regions of the brain results in superior performance. Employment of EEG neurofeedback during the aiming period of target shooting designed to reduce cortical activation resulted in improved performance in skilled marksmen. Such an effect implies that refinement of cortical activity is causally related to performance. Recently, we examined cerebral cortical dynamics during the stress of competitive target shooting and observed increased activation and cortico-cortical communication between non-motor and motor regions relative to a practice-alone condition. As predicted, this finding was associated with degradation of shooting performance. These findings imply that neurofeedback targeted to brain regions related to emotional responding may preserve the cortical dynamics associated with superior performance resulting in improved accuracy of precision aiming performance.

Kober, SE., Witte, M., Stangl, M., Vaijarnae, A., Neuper, C. & Wood, G. (2014). Shutting down sensory motor interference unblocks the networks for stimulus processing: An SMR neurofeedback training study. Clinical Neurophysiology:April 13. OBJECTIVE: In the present study, we investigated how the electrical activity in the sensorimotor cortex contributes to improved cognitive processing capabilities and how SMR (sensorimotor rhythm, 12-15Hz) neurofeedback training modulates it. Previous evidence indicates that higher levels of SMR activity reduce sensorimotor interference and thereby promote cognitive processing. METHODS: Participants were randomly assigned to two groups, one experimental (N=10) group receiving SMR neurofeedback training, in which they learned to voluntarily increase SMR, and one control group (N=10) receiving sham feedback. Multiple cognitive functions and electrophysiological correlates of cognitive processing were assessed before and after 10 neurofeedback training sessions. RESULTS: The experimental group but not the control group showed linear increases in SMR power over training runs, which was associated with behavioural improvements in memory and attentional performance. Additionally, increasing SMR led to a more salient stimulus processing as indicated by increased N1 and P3 event-related potential amplitudes after the training as compared to the pre-test. Finally, functional brain connectivity between motor areas and visual processing areas was reduced after SMR training indicating reduced sensorimotor interference. CONCLUSIONS: These results indicate that SMR neurofeedback improves stimulus

processing capabilities and consequently leads to improvements in cognitive performance. SIGNIFICANCE: The present findings contribute to a better understanding of the mechanisms underlying SMR neurofeedback training and cognitive processing and implicate that SMR neurofeedback might be an effective cognitive training tool.

Kober, SE., Witte, M., Ninaus, M., Neuper, C. & Wood, G. (2013). Learning to modulate one's own brain activity: The effect of spontaneous mental strategies. Frontiers in Human Neuroscience: Oct 18(7). 695. Using neurofeedback (NF), individuals can learn to modulate their own brain activity, in most cases electroencephalographic (EEG) rhythms. Although a large body of literature reports positive effects of NF training on behavior and cognitive functions, there are hardly any reports on how participants can successfully learn to gain control over their own brain activity. About one third of people fail to gain significant control over their brain signals even after repeated training sessions. The reasons for this failure are still largely unknown. In this context, we investigated the effects of spontaneous mental strategies on NF performance. Twenty healthy participants performed either a SMR (sensorimotor rhythm, 12-15 Hz) based or a Gamma (40-43 Hz) based NF training over ten sessions. After the first and the last training session, they were asked to write down which mental strategy they have used for self-regulating their EEG. After the first session, all participants reported the use of various types of mental strategies such as visual strategies, concentration, or relaxation. After the last NF training session, four participants of the SMR group reported to employ no specific strategy. These four participants showed linear improvements in NF performance over the ten training sessions. In contrast, participants still reporting the use of specific mental strategies in the last NF session showed no changes in SMR based NF performance over the ten sessions. This effect could not be observed in the Gamma group. The Gamma group showed no prominent changes in Gamma power over the NF training sessions, regardless of the mental strategies used. These results indicate that successful SMR based NF performance is associated with implicit learning mechanisms. Participants stating vivid reports on strategies to control their SMR probably overload cognitive resources, which might be counterproductive in terms of increasing SMR power.

Leach, J., Bulpin, K., Khan, S., Rass, A., ChammoropPremuzic, T., Nelson, C., Gruzelier, J. (2006). Controlled study of neurofeedback with novice singers. *Society of Applied Neuroscience Conference presentation*. Swansea. This is a pilot for a larger study with the aim of extending with novice musicians the findings of Egner and Gruzelier (2003) with elite musicians. They demonstrated professionally significant gains in artistry in music performance following alpha/theta training, but not with SMR or beta

1training, nor with aerobic exercise or mental skills/rehearsal training or the Alexander technique. Here are presented the results of 12 novice singers from London music colleges who were randomly assigned in equal numbers to ten sessions over two months of alpha/theta (A/T) training or SMR training. The study and analysis are ongoing. Results are presented for pre and post training assessment of music performance, attention, memory, mood and processes associated with creativity. There was evidence of significant within and between session learning in increasing the theta/alpha ratio ($p<0.001$ & $p<0.047$), but not in elevating the SMR/theta ratio. Despite the latter limitation semantic cued memory increased in the SMR group in support of Vernon et al (2003) ($p<0.049$, one tailed). Otherwise there were several suggestive differential effects advantaging the A/T group over the SMR group in music performance, creativity and attention, the latter in the direction of the results of Egner and Gruzelier (2004) though not reaching significance in their study. The Test of Variables of Attention (TOVA) showed an increase in sensitivity (d') with A/T ($p<0.04$) and the reverse with SMR (Group x Time $p<0.04$), largely due to a reduction in omission errors with A/T and the opposite mean change in the SMR group (G x T, $p<0.066$). There was also a reduction in RT variability ($p<0.012$). Support for associations with creativity followed improvement in flexibility on the Guildford Alternative Uses Test ($p<0.055$), and the rule breaking subscale of the Adaptor/Innovator Test ($p<0.022$). The Baddeley Sentence Checking Test which involves working memory and reasoning was also advantaged ($p<0.047$) by A/T training. Finally blind lay evaluations from video clips of expressiveness, confidence and stage presence disclosed improvement following A/T (all $p<0.001$) in contrast to SMR training (G x T, all $p<0.002$).

Markovska-Simoska S, Pop-Jordanova N, Georgiev D. (2008). Simultaneous EEG and EMG biofeedback for peak performance in musicians. *Prilozi*, 29(1): 239-252. The aim of this study was to determine the effects of alpha neurofeedback and EMG biofeedback protocols for improvement of musical performance in violinists. The sample consisted of 12 music students (10 violinists and 2 viola players) from the Faculty of Music, Skopje (3 males, mean age of 20 +/- 0 and 9 females, mean age = 20.89 +/- 2.98). Six of them had a low alpha peak frequency (APF) (< 10 Hz), and six a high APF (**>** 10 Hz). The sample was randomized in two groups. The students from the experimental group participated in 20 sessions of biofeedback (alpha/EMG), combined with music practice, while the students from the control group did only music practice. Average absolute power, interhemispheric coherence in the alpha band, alpha peak frequency (APF), individual alpha band width (IABW), amount of alpha suppression (AAS) and surface forehead integrated EMG power (IEMG), as well as a score on musical performance and inventories measuring anxiety, were assessed. Alpha-

EEG/EMG-biofeedback was associated with a significant increase in average alpha power, APF and lABW in all the participants and with decreases in lEMG only in high-APF musicians. The biofeedback training success was positively correlated with the alpha power, lcoH, APF, lABW and baseline level of APF and lABW. Alpha-EEG/EMG biofeedback is capable of increasing voluntary self-regulation and the quality of musical performance. The efficiency of biofeedback training depends on the baseline EEG alpha activity status, in particular the APF.

Raymond, J., Sajid, I., Parkinson, L. A., & Gruzelier, J. H. (2005). Biofeedback and dance performance: A preliminary investigation. ***Applied Psychophysiology & Biofeedback*****, 30(1), 65-74.** Alpha-theta neurofeedback has been shown to produce professionally significant performance improvements in music students. The present study aimed to extend this work to a different performing art and compare alpha-theta neurofeedback with another form of biofeedback: heart rate variability (HRV) biofeedback. Twenty-four ballroom and Latin dancers were randomly allocated to three groups, one receiving neurofeedback, one HRV biofeedback and one no intervention. Dance was assessed before and after training. Performance improvements were found in the biofeedback groups but not in the control group. Neurofeedback and HRV biofeedback benefited performance in different ways. A replication with larger sample sizes is required.

Sherlin, LH., Larson, SC. & Sherlin, RM. (2013). Developing a performance training approach for baseball: A process analysis with descriptive data. Applied Psychophysiology and Biofeedback:38(1). 29-44. Neurofeedback may be useful for improving sports performance but few studies have examined this potential. Here we present data of five development players from a major league baseball team. The aims were to evaluate the feasibility of conducting sessions within a professional organization, assess changes in quantitative electroencephalograph (QEEG), NeuroPerformance Profile™, and report qualitative self-report data before and after brain training. The EEG was recorded with 19 electrodes for 20 min of baseline conditions and approximately 21 min of a continuous performance test. The fast Fourier transform analysis provided average cross-spectral matrices for bands delta (1-3.5 Hz), theta (4-7.5 Hz), alpha (8-12 Hz), low beta (13-16 Hz), beta 1 (13-21 Hz), beta 2 (22-32 Hz), and gamma (32-45 Hz) from the pre and post intervention evaluations in the baseline condition of eyes open. The continuous performance test metrics included the errors of omission, errors of commission, response time and response time variability. The 9 scales of the NeuroPerformance Profile™ were examined. The QEEG data, CPT data and

NeuroPerformance Profile™ data were all compared between the pre and post 15 sessions of brain training using a within subject paired t test design corrected for multiple comparisons using false discovery rate method. Following brain training, comparative QEEG, CPT and NeuroPerformance Profile™ analyses illustrated significant differences. The QEEG findings of all participants illustrated significant changes within the training parameters but also across other frequency bands and electrode sites. Overall, the positive findings in both objective and subjective measures suggest further inquiry into the utility of brain training for performance enhancement with the specific application of sport is warranted. Particularly QEEG and CPT gains were noted in the areas that correspond to client self-report data demonstrating improvement in attention, decreased intrusive thought patterns and improvements in sleep patterns.

Sokhadze, E. (2012). Peak performance training using prefrontal EEG biofeedback. *Biofeedback*, 39, 7-15. The use of biofeedback training to self-regulate EEG patterns with the aim of recovering or optimizing function and behavioral performance is becoming increasingly established. The most reasonable approach is to learn to generate and maintain optimal brain wave patterns and produce associated peak performance states on demand. We report two studies where 12 sessions of prefrontal EEG feedback were used to improve performance in both clinical and nonclinical populations. Neurofeedback using Focus, Alertness, and 40 Hz (Neureka!) measures resulted in improved selective attention and other cognitive functions. We discuss other potential applications of neurofeedback in the areas of “under-pressure” activity, where peak performance state is an essential part of the job, such as in sports or the performing arts, as well as for human operators, such as air traffic dispatchers and military personnel on duty.

Thompson, T., Steffert, T., Ros, T., Leach, J., & Gruzelier, J. (2008). EEG applications for sport and performance. ***Methods*****, 45, 279-288**. One approach to understanding processes that underlie skilled performing has been to study electrical brain activity using electroencephalography (EEG). A notorious problem with EEG is that genuine cerebral data is often contaminated by artifacts of non-cerebral origin. Unfortunately, such artifacts tend to be exacerbated when the subject is in motion, meaning that obtaining reliable data during exercise is inherently problematic. These problems may explain the limited number of studies using EEG as a methodological tool in the sports sciences. This paper discusses how empirical studies have generally tackled the problem of movement artifact by adopting alternative paradigms, which avoid recording during actual physical exertion. Moreover, the specific challenges that motion presents to obtaining reliable EEG data are discussed along with practical and

computational techniques to confront these challenges. Finally, as EEG recording in sports is often underpinned by a desire to optimize performance, a brief review of EEG-biofeedback and peak performance studies is also presented. A knowledge of practical aspects of EEG recording along with the advent of new technology and increasingly sophisticated processing models offer a promising approach to minimizing, if perhaps not entirely circumventing, the problem of obtaining reliable EEG data during motion.

Witte, M., Kober, SE., Ninaus, M., Neuper, C. & Wood, G. (2013). Control beliefs can predict the ability to up-regulate sensorimotor rhythm during neurofeedback training. Frontiers in Human Neuroscience:15(7). 478. Technological progress in computer science and neuroimaging has resulted in many approaches that aim to detect brain states and translate them to an external output. Studies from the field of brain-computer interfaces (BCI) and neurofeedback (NF) have validated the coupling between brain signals and computer devices; however a cognitive model of the processes involved remains elusive. Psychological parameters usually play a moderate role in predicting the performance of BCI and NF users. The concept of a locus of control, i.e., whether one's own action is determined by internal or external causes, may help to unravel inter-individual performance capacities. Here, we present data from 20 healthy participants who performed a feedback task based on EEG recordings of the sensorimotor rhythm (SMR). One group of 10 participants underwent 10 training sessions where the amplitude of the SMR was coupled to a vertical feedback bar. The other group of ten participants participated in the same task but relied on sham feedback. Our analysis revealed that a locus of control score focusing on control beliefs with regard to technology negatively correlated with the power of SMR. These preliminary results suggest that participants whose confidence in control over technical devices is high might consume additional cognitive resources. This higher effort in turn may interfere with brain states of relaxation as reflected in the SMR. As a consequence, one way to improve control over brain signals in NF paradigms may be to explicitly instruct users not to force mastery but instead to aim at a state of effortless relaxation.

DEPRESSION AND BIPOLAR DISORDER

Allen, J. B.., & Cavendar, J. H. (1996). Biofeedback alters EEG asymmetry. *Psychophysiology*, 33(suppl), S17, Individual differences in resting asymmetrical frontal brain activity have been found to predict subsequent emotional responses. The question of whether frontal brain asymmetry can cause emotional responses has yet to be addressed. Biofeedback training designed to alter the asymmetry of frontal brain activity was therefore examined. Eighteen right-handed female participants were randomly assigned to receive biofeedback training designed to increase right frontal alpha relative to left frontal alpha (n = 9) or to receive training in the opposite direction (n = 9). Five consecutive days of biofeedback training provided signals of reward or nonreward depending on whether the difference between right (F4) and left (F3) frontal alpha exceeded a criterion value in the specified direction. Systematic alterations of frontal EEG asymmetry were observed as a function of biofeedback training. Moreover, subsequent self-reported affect and facial muscle activity in response to emotionally evocative film clips were influenced by the direction of biofeedback training.

Baehr, E., Miller, E., Rosenfeld, J. P., & Baehr, R. (2004). Changes in frontal brain asymmetry associated with premenstrual dysphoric disorder: A single case study. *Journal of Neurotherapy*, 8(1), 29-42. *Background*. In a pilot study, Baehr (2001) reports changes in frontal cortical alpha asymmetry during the luteal phase of the menstrual cycle were documented in five depressed women who also experienced Premenstrual Dysphoric Disorder (PMDD). In this paper detailed data is presented for one of these subjects and two comparison subjects who were part of the first study. The goal was two-fold: (a) to study how patterns of mood changes during the luteal phase of the menstrual cycle correlated with changes in frontal alpha brainwave asymmetry, and (b) to determine whether treatment strategies, tailored to ameliorate symptoms, would be reflected in brainwave changes. *Method*. Neurofeedback, medical interventions, and prospective charting were collected over a period of six months for one patient. These data were compared with data collected for two monthly cycles from two non-PMDD comparison subjects. *Results*. The patient responded well to the neurofeedback protocol for depression and was normalizing her scores by the second week in treatment except for setbacks which occurred during the luteal phase of her menstrual cycle. Extreme mood changes correlated with changes in brainwave asymmetry during this period. A combination of neurofeedback and medication worked

to stabilize her mood swings and asymmetry scores. *Conclusion*. This case study demonstrated how brainwave changes in frontal alpha asymmetry occurred during the luteal phase of the menstrual cycle in a woman who suffered from PMDD. Two comparison subjects, who were undergoing similar treatment for depression but did not suffer from PMDD, had stable alpha asymmetry scores during the entire menstrual cycle. Anomalies in serotonergic and/or gabergic function in the luteal phases of PMDD are pinpointed as possible underlying factors in this disorder.

Baehr, E., Rosenfeld, J. P., & Baehr, R. (1997). The clinical use of an alpha asymmetry protocol in the neurofeedback treatment of depression: Two case studies. *Journal of Neurotherapy*, 2(3), 10-23. In this study we are presenting case studies of two depressed women who were trained with more than 34 sessions each of EEG biofeedback (neurofeedback) using an Alpha Asymmetry protocol, the purpose of this training was to determine if depression could be alleviated when the subjects learned to increase the activation of the left hemisphere and/ or decrease the activation of the right hemisphere. The MMPI-2 was administered before and after training to measure changes in personality factors, including depression. The results suggest that Alpha Asymmetry neurofeedback training may be an effective adjunct to psychotherapy in the treatment of certain types of mood disorders.

Baehr, E., Rosenfeld, J. P., & Baehr, R. (2001). Clinical use of an alpha asymmetry neurofeedback protocol in the treatment of mood disorders: Follow-up study one to five years post therapy. *Journal of Neurotherapy*, 4(4), 11-18.
Background: This study reports on three of six patients who have completed an average of 27 neurofeedback sessions using a patented alpha asymmetry protocol for the treatment of depression. *Method:* The follow-up data, from one to five years post therapy, were derived from a single session re-test using the same alpha asymmetry protocol and the Beck Depression Inventory. *Results:* The three patients originally diagnosed as having unipolar depression reached the training criteria for the non-depressed range by the end of their initial training, and they have maintained their normal scores for right hemisphere alpha asymmetry training over time. The follow-up Beck Depression Inventory scores were also within the normal range. *Discussion:* This finding is contrary to the previously held demonstrations by Davidson and Henriques regarding the stability of decreased left anterior cortical activation in remitted depression. While some patients have reported mood changes with life's vicissitudes, none have experienced clinical depression since they have terminated therapy.

Berg, K., Siever, D. (2009). A controlled comparison of audio-visual entrainment for treating Seasonal Affective Disorder. Journal of Neurotherapy 13(3), 166 - 175. *Introduction*. Seasonal Affective Disorder (SAD) affects up to 6% of the population, primarily in the winter months and at higher latitudes. *Methods*. Light-box therapy has been the traditional intervention for SAD, where the individual is exposed to a bright light for substantial periods in an effort to replace the lack of sunshine. Audio-visual entrainment (AVE) is a technique using flashing lights through a pair of specially designed glasses and pulses of tones through headphones. The expectation of AVE is to affect brain wave activity through auditory and visual stimulation at specific frequencies. The objective of this study was to determine if AVE is a viable treatment for SAD. The study involved 74 participants in a comparison design with a control group (no flashing lights or pulsed tones) and an AVE group that received a placebo treatment (AVE at 1 Hz flashing lights and pulsed tones) for 2 weeks, followed by an active treatment phase (20 Hz flashing lights and pulsed tones) for another 2 weeks. *Results*. The results indicated that the placebo phase produced mild reductions in depression and no improvements in anxiety sensitivity, whereas 20 Hz AVE reduced both depression and anxiety symptoms. *Conclusion*. The 20 Hz AVE treatment condition also produced significant improvements in social life with the family and at work, and increased happiness and energy. The 20-Hz treatment also produced a significant decrease in eating, appetite, and carbohydrate intake.

Brenninkmeijer J. (2010). Taking care of one's brain: how manipulating the brain changes people's selves. *Hist Human Sci*. 2010;23(1):107-26. The increasing attention to the brain in science and the media, and people's continuing quest for a better life, have resulted in a successful self-help industry for brain enhancement. Apart from brain books, foods and games, there are several devices on the market that people can use to stimulate their brains and become happier, healthier or more successful. People can, for example, switch their brain state into relaxation or concentration with a light-and-sound machine, they can train their brain waves to cure their Attention Deficit Hyperactivity Disorder (ADHD) or solve their sleeping problems with a neurofeedback device, or they can influence the firing of their neurons with electric or magnetic stimulation to overcome their depression and anxieties. Working on your self with a brain device can be seen as a contemporary form of Michel Foucault's "technologies of the self." Foucault described how since antiquity people had used techniques such as reading manuscripts, listening to teachers, or saying prayers to "act on their selves" and control their own thoughts and behaviours. Different techniques, Foucault stated, are based on different precepts and constitute different selves. I follow Foucault by stating that using a brain device for self-improvement indeed constitutes a

new self. Drawing on interviews with users of brain devices and observations of the practices in brain clinics, I analyse how a new self takes shape in the use of brain devices; not a monistic (neuroscientific) self, but a "layered" self of all kinds of entities that exchange and control each other continuously.

Cantor, D.S., Stevens, E. (2009). QEEG correlates of auditory-visual entrainment treatment efficacy of refractory depression. *Journal of Neurotherapy* 13(2), 100 - 108. *Introduction.* It is well established that the number of people diagnosed and suffering from depression is on the increase. Many of these patients are not responsive to first-line pharmacological intervention or simply cannot use medications for other reasons. As such, there has been a growing need for nonmedication approaches to treatment. The purpose of this study was to examine the use of auditory-visual EEG entrainment (AVE) at a 14 Hz (beta) frequency to decrease symptoms of depression with corresponding changes in neurophysiology. *Method.* Sixteen participants ranged in age from 20 to 67 years and were screened utilizing the Beck Depression Inventory-II (BDI-II) and broken into two groups of 8 (simulated, AVE treatment groups), with a cross-over design. Both groups were given the BDI-II and QEEG testing at baseline, 4 weeks following either AVE or simulated treatment, and then again after an additional 4 weeks and a switch in treatment in the cross-over design. *Results.* Results revealed significant reduction of depression only after the 4 weeks on AVE therapy of the BDI-II scores ($p > .01$). QEEG scores adjusted for normal age deviations demonstrate significant EEG change scores over time in cortical regions associated with mood regulation. *Conclusion.* The findings indicate that AVE therapy may be a viable nonmedication therapeutic intervention.

Choi SW, Chi SE, Chung SY, Kim JW, Ahn CY, Kim HT. (2011). Is alpha wave neurofeedback effective with randomized clinical trials in depression? A pilot study. *Neuropsychobiology.* 2011;63(1):43-51. Frontal asymmetric activation has been proposed to be the underlying mechanism for depression. Some case studies have reported that the enhancement of a relative right frontal alpha activity by an asymmetry neurofeedback training leads to improvement in depressive symptoms. In the present study, we examined whether a neurofeedback training designed to increase the relative activity of the right frontal alpha band would have an impact on symptoms of depressive subjects suffering from emotional, behavioral, and cognitive problems. Our results indicated that the asymmetry neurofeedback training increased the relative right frontal alpha power, and it remained effective even after the end of the total training sessions. In contrast to the training group, the placebo control group did not show a difference. The neurofeedback training had profound effects on emotion and cognition.

First, we replicated earlier findings that enhancing the left frontal activity led to alleviation of depressive symptoms. Moreover, cognitive tests revealed that the asymmetry training improved performance of executive function tests, whereas the placebo treatment did not show improvement. We preliminarily concluded that the asymmetry training is important for controlling and regulating emotion, and it may facilitate the left frontal lobe function.

Escalano, C., Navarro-Gil, M., Garcia-Campayo, J & Minguez, J. (2013). EEG-based upper-alpha neurofeedback for cognitive enhancement in major depressive disorder: a preliminary, uncontrolled study. Conference Proceedings: IEEE 2103:6293-6. Conditioning of the upper-alpha rhythm to improve cognitive performance in healthy users by means of neurofeedback (NF) has been evaluated by several studies, however its effectiveness in people with severe cognitive deficits, such as depressive subjects, remains underexplored. This paper reports on a preliminary uncontrolled study to assess the effects of an upper-alpha NF intervention on patients with major depressive disorder (MDD). The NF effects on the EEG and cognitive performance were assessed. The EEG results showed that patients were able to modulate the upper-alpha rhythm in task-related EEG and during training, in both cases across the executions of the NF sessions, and pre and post within each session. The behavioral results showed the effectiveness of this intervention in a variety of cognitive functions such as working memory, attention, and executive functions.

Hammond, D. C. (2001). Neurofeedback treatment of depression with the Roshi. *Journal of Neurotherapy*, 4(2), 45-56. *Introduction*. A patient with severe, medication resistant depression was found to have the frontal alpha asymmetry described in Davidson's (1998a) research as demonstrating a predisposition to depression. *Treatment*. Initial sessions of EEG neurofeedback using Rosenfeld's (1997) protocol for correcting the alpha asymmetry were discouraging, actually producing slight negative change. Therefore, treatment shifted to using the Roshi, a two channel unit combining neurofeedback and photic stimulation, doing primarily left hemisphere beta training. *Results*. The very first Roshi session produced positive changes, and within five sessions the patient reported feeling less depressed and more energetic. At the conclusion of thirty training sessions, objective testing documented dramatic reductions in depression, somatic symptoms, overemotionality, anxiety, rumination, and fatigue. *Discussion*. In support of Henriques and Davidson's (1991) belief that hypoactivation of the left hemisphere results in an “approach deficit” and more withdrawal behavior, post-testing and interview data also documented that the patient had become less withdrawn, more active, sociable, and less distrustful. Eight and one-half month follow-up

documented maintenance of changes. Continued exploration of left hemisphere beta protocols in treating depression, and of the combined use of neurofeedback with photic stimulation are encouraged.

Hardman, E., Gruzelier, J., Chessman, K., Jones, C., Liddiard, D., Schleichert, H., & Birbaumer, N. (1997). Frontal interhemispheric asymmetry: Self-regulation and individual differences in humans. ***Neuroscience Letters,*** **221, 117-120.** Sixteen subjects naive to biofeedback learned lateralised interhemispheric control of slow cortical potentials (SCPs) across electrode sites F3-F4 during three sessions of visual electroencephalograph (EEG) biofeedback. Subjects were required to generate slow negativity shifts either towards the left or the right hemisphere in sixty pseudorandomly ordered trials per session. Group 1 (n = 8) were told to use emotional strategies in the task (positive emotions for left hemisphere activation, negative emotion for right hemisphere activation), group 2 received no guidance. Both groups received feedback in the form of an on-screen rocket-ship, initially centrally placed, which rose to indicate an increase in left hemisphere negativity (relative to the right hemisphere) and fell to indicate an increase in right hemisphere negativity (relative to the left hemisphere). A 2 x 3 x 3 x 2 ANOVA (group x session x block x trial) showed no performance differences between the strategy and no strategy groups. Both groups learned to produce correct direction shifts in the final third of each session during both trial types ($P < 0.001$). The no strategy group showed a particularly strong within session learning effect ($P < 0.0037$) with poor performance in the early part of the sessions, and strong shifts at the end. Subjects high on withdrawal showed stronger rightward shifts in keeping with right hemisphere involvement in behavioural withdrawal. This is the first demonstration of self regulation of interhemispheric frontal asymmetry.

Jenkins, P., & Moore, W. H. (1985). The effects of visual feedback on hemispheric alpha asymmetries and reported processing strategies: A single-subject experimental design. ***Brain & Cognition*****, 4(1), 47-58.** A double reversal single-subject experimental design was used to study the effects of visual feedback on the hemispheric alpha asymmetries of a male subject during a linguistic task. Results indicated that the subject demonstrated flexibility in hemispheric alpha and corresponding processing strategies employed when an alpha biofeedback procedure was used. These results provide further support for the notion that right and left hemispheric activation is associated with different, yet compatible, cognitive strategies and that both can be manipulated under conditions of feedback.

Kotchoubey, B., Schleichert, H., Lutzenberger, W., Anokhin, A. P., & Birbaumer, N. (1996). Self-regulation of interhemispheric asymmetry in humans. *Neuroscience Letters*, 215, 91-94. Five healthy right-handed subjects learned to control hemispheric asymmetry with biofeedback of the amplitude difference of slow cortical potentials between the left and the right precentral areas. Six training sessions were conducted with subject I, 12 sessions with subjects II and III, and 14 sessions, with subjects IV and V. Performance of four out of five subjects improved continuously as a function of sessions. Towards the end of training, these subjects demonstrated highly significant differentiation between conditions where right versus left precentral negativity was required. In subject V, no improvement was observed after 14 training sessions. The data indicate that most subjects can learn to self-generate fast electroencephalograph (EEG) differences between the left and the right sensorimotor cortical regions.

Kumano, H., Horie, H., Shidara, T., Kuboki, T. et al. (1996). Treatment of a depressive disorder patient with EEG-driven photic stimulation. *Biofeedback & Self-Regulation,* 21(4), 323-334. This study examined the effects of electroencephalographic-(EEG-) driven photic stimulation on a case of depressive disorder, as measured by a psychometric test of mood states, EEG parameters, and several autonomic indices. The EEG-driven photic stimulation enhances the alpha rhythm of brain waves using photic signals, the brightness of which is modulated by a subject's own alpha rhythm. The patient was a 37-year-old businessman, who was treated for depression with medication during the 13 months prior to his first visit to our hospital. He underwent two sets of inpatient treatment sessions, comprising first 16 and then 18 treatment sessions. The treatments brought about the following changes: an improvement in general mood state, alpha rhythm increase, cardiac parasympathetic suppression, and increased skin conductance level. In addition, significant correlations between alpha rhythm increase and cardiac parasympathetic suppression or cardiac sympathetic predominance were observed with each inpatient treatment. Significant correlations between alpha rhythm increase, cardiac parasympathetic suppression, or cardiac sympathetic predominance and the improvement of general mood state were also observed. Thus, from these observations, it was concluded that the alpha enhancement induced by EEG-driven photic stimulation produced an improvement in the patient's depressive symptomatology connected with cardiac parasympathetic suppression and sympathetic predominance.

Linden DE, Habes I, Johnston SJ, Linden S, Tatineni R, Subramanian L, Sorger B, Healy D, Goebel R. (2012). Real-time self-regulation of emotion networks in patients with depression. *PLoS One.* 2012;7(6):e38115. doi: 10.1371/journal.pone.0038115. Epub 2012 Jun 4. Many patients show no or incomplete

responses to current pharmacological or psychological therapies for depression. Here we explored the feasibility of a new brain self-regulation technique that integrates psychological and neurobiological approaches through neurofeedback with functional magnetic resonance imaging (fMRI). In a proof-of-concept study, eight patients with depression learned to upregulate brain areas involved in the generation of positive emotions (such as the ventrolateral prefrontal cortex (VLPFC) and insula) during four neurofeedback sessions. Their clinical symptoms, as assessed with the 17-item Hamilton Rating Scale for Depression (HDRS), improved significantly. A control group that underwent a training procedure with the same cognitive strategies but without neurofeedback did not improve clinically. Randomised blinded clinical trials are now needed to exclude possible placebo effects and to determine whether fMRI-based neurofeedback might become a useful adjunct to current therapies for depression.

Peeters, F., Oehlen, M., Ronner, J., van Os, J & Lousberg, R. (2014). Neurofeedback as a treatment for major depressive disorder - A pilot study. PLoS One Mar 18;9(3). Biofeedback potentially provides non-invasive, effective psychophysiological interventions for psychiatric disorders. The encompassing purpose of this review was to establish how biofeedback interventions have been used to treat select psychiatric disorders [anxiety, autistic spectrum disorders, depression, dissociation, eating disorders, schizophrenia and psychoses] to date and provide a useful reference for consultation by clinicians and researchers planning to administer a biofeedback treatment. A systematic search of EMBASE, MEDLINE, PsycINFO, and WOK databases and hand searches in Applied Psychophysiology and Biofeedback, and Journal of Neurotherapy, identified 227 articles; 63 of which are included within this review. Electroencephalographic neurofeedback constituted the most investigated modality (31.7%). Anxiety disorders were the most commonly treated (68.3%). Multi-modal biofeedback appeared most effective in significantly ameliorating symptoms, suggesting that targeting more than one physiological modality for bio-regulation increases therapeutic efficacy. Overall, 80.9% of articles reported some level of clinical amelioration related to biofeedback exposure, 65.0% to a statistically significant ($p < .05$) level of symptom reduction based on reported standardized clinical parameters. Although the heterogeneity of the included studies warrants caution before explicit efficacy statements can be made. Further development of standardized controlled methodological protocols tailored for specific disorders and guidelines to generate comprehensive reports may contribute towards establishing the value of biofeedback interventions within mainstream psychiatry.

Peeters, F., Ronner, J., Bodar, L., van Os, J., Louisberg, R. (2013). Validation of a neurofeedback paradigm: Manipulating frontal EEG alpha-activity and its impact on

mood. Int J Psychophysiol. doi: 10.1016/j.ijpsycho.2013.06.010. It is claimed that neurofeedback (NF) is an effective treatment for a variety of psychiatric disorders. NF, within an operant conditioning framework, helps individuals to regulate cortical electroencephalographic (EEG) activity while receiving feedback from a visual or acoustic signal. For example, changing asymmetry between left and right frontal brain alpha activity by NF, is claimed to be an efficacious treatment for major depressive disorder. However, the specificity of this intervention in occasioning electrophysiological changes at target locations and target wave-frequencies, and its relation to changes in mood, has not been established. During a single session of NF, it was tested if the balance between left and right frontal alpha-activity could be changed, regardless of direction, in 40 healthy females. Furthermore, we investigated whether this intervention was electrophysiologically specific and if it was associated with changes in mood. Participants were able to decrease or increase frontal alpha-asymmetry during the intervention. However, no changes in mood were observed. (*Note from bibliographer: one session would rarely provide changes in behavior*). Changes in EEG activity were specific in terms of location and wave-frequency.

Putnam, J. A., (2001). EEG biofeedback on a female stroke patient with depression: A case study. *Journal of Neurotherapy*, 5(3), 27-38. *Background*. This single case concerns the treatment of a 71-year-old female stroke patient. The patient's MRI revealed that the location of the stroke was in the right side basal ganglia with damage extending into the anterior limb of the internal capsule. She presented with a virtual paralysis of the left side of her body (hemiplegia with immobilized left arm, contracted fist, minimal motor control over left leg, absence of muscle tonus in left side of face and slurred, monotonic speech). *Method*. The client was provided with EEG biofeedback training on a one to two half-hour sessions per week schedule. Bipolar montages were used along with single site protocols. This was based largely on the idea of reciprocal communication loops between widely separated cortical generators. It was thought that encouraging communication between cortical sites would have a beneficial impact on impairments related to both functional and structural damage. EEG training protocols included SMR (12-15 Hz) enhancement at C4, C4-Pz and T3-T4 with theta suppression; beta (15-18 Hz) enhancement with theta suppression at C3, C3-Fpz and at C3-Fp1. *Results*. Patient showed significant improvement in gross motor control and range of movement of left arm and leg. The most dramatic improvement was observed in speech (articulation, strength and tone). While substantial improvements were observed in motor ability, restoration of mood stability proved somewhat more elusive. Since she was receiving additional treatment (physical therapy and medication management), it is impossible to attribute the improvement in functioning solely to the EEG training.

However, the consensus among the attending medical personnel was that the improvements noted above took place with unusual expeditiousness. *Discussion*. When performing EEG biofeedback it may be most practical to adopt an "exercise model" approach in which the regulatory mechanisms in the brain are challenged through the sequential use of multiple protocol configurations. In this case several different training protocols proved useful in her ongoing recovery. While improvements in functioning were a result of a concerted effort involving multiple therapeutic interventions, it is likely that neurofeedback played a vital synergistic role.

Raymond, J., Varney, C., Parkinson, L. A., & Gruzelier, J. H. (2005). The effects of alpha/theta neurofeedback on personality and mood. *Cognitive Brain Research,* 23, 287-292. Alpha/theta neurofeedback has been shown to be successful both in treating addictions and in enhancing artistry in music students. How its effects are mediated are not yet clear. The present study aimed to test the hypothesis that alpha/theta neurofeedback works inter alia by normalising extreme personality and raising feelings of well-being. 12 participants with high scores for Withdrawal (as measured by the PSQ) were given either alpha/theta neurofeedback or mock feedback and their personality and mood were assessed. Withdrawal scores on the PSQ-80 were not found to change in either group but significant effects were found for the Profile Of Mood States (POMS), with real feedback producing higher overall scores than mock feedback ($P = 0.056$). Real feedback caused participants to feel significantly more energetic ($P < 0.01$) than did mock feedback. Sessions of real feedback made participants feel more composed ($P < 0.01$), agreeable ($P < 0.01$), elevated ($P < 0.01$) and confident ($P < 0.05$), whilst sessions of mock feedback made participants feel more tired ($P < 0.05$), yet composed ($P < 0.01$). These findings suggest that, whilst 9 sessions of alpha/theta neurofeedback was insufficient to change personality, improvements in mood may provide a partial explanation for the efficacy of alpha/theta neurofeedback.

Robbins, J. (2000). On the track with neurofeedback. A new treatment may help with problems from ADD to depression, sleep disorders and epilepsy. *Newsweek*. 2000 Jun 19;135(25):76. (No abstract)

Rockstroh, B., Elbert, T., Birbaumer, N. J., & Lutzenberger, W. (1990). Biofeedback-produced hemispheric asymmetry of slow cortical potentials and its behavioural effects. *International Journal of Psychophysiology*, 9, 151-165. Two studies served to examine behavioural effects of slow cortical potentials (SPs). SPs were manipulated by means of a biofeedback procedure. The ability of human subjects to alter SPs differentially between the two hemispheres--specifically over the lateral aspects of the

central sulcus--was tested by providing feedback of the SP difference between C3 and C4. In Expt. I, 21 of the 45 subjects produced hemispheric asymmetries of more than 2 microV between C3 and C4 on an average after 80 trials of analogue, continuous and immediate feedback. In Expt. II, SP changes were fed back digitally at the end of each trial. Within 120 trials, 20 of the 48 subjects reached the criterion of a minimum 2-microV difference in SPs between C3 and C4 on the average. Average differentiation remained significantly below the SP differentiations achieved for continuous feedback. Trials with feedback were followed by 'task' trials without feedback, during which subjects were still requested to produce SP changes but also had to complete a task: Either sensorimotor tasks (Expt. I) or forced choice handedness tasks (Expt. II) were presented to evaluate behavioural consequences of hemispheric SP differences. In subjects achieving the required SP differentiation it affected the behavioural output in agreement with the known functions of the respective cortical area.

Rosenfeld, J. P., Baehr, E., Baehr, R., Gotlib, I. H., & Ranganath, C. (1996). Preliminary evidence that daily changes in frontal alpha asymmetry correlate with changes in affect in therapy sessions. ***International Journal of Psychophysiology,*** **23, 137-141.** Frontal EEG alpha asymmetry was recorded from five depressed outpatients during early EEG biofeedback sessions. Mood was assessed prior to and after each session, and affect change scores were also derived by subtracting pre-session from post-session scores. Alpha magnitude was obtained via Fast Fourier Transforms. All scores (EEG alpha asymmetry and affect) were converted to deviation scores by subtracting each patient's daily score from that patient's mean across all available sessions for that patient. Pearson correlations were then computed between asymmetry and affect scores using the deviation scores combined over patients. There was little evidence of correlation between day-to-day asymmetry score and any single affect score. Strong correlations were obtained, however, between asymmetry score and affect change score and, in particular, between asymmetry score and change in positive affect.

Rosenfeld, J. P., Cha, G., Blair, T., & Gotlib, I. (1995). Operant biofeedback control of left-right frontal alpha power differences. ***Biofeedback & Self-Regulation*****, 20, 241-258.** Two experiments were done with subjects from a paid pool of undergraduates. In each study, there were five 1-hour sessions on each of 5 days: (1) Baseline: Rewards given for randomly selected 20% of the 700-ms sequential epochs; mean and SD of baseline power differences determined. 2) Exploration: Subjects were rewarded when right minus left alpha differences in an epoch were greater than the baseline mean plus about .85 SD (p = .20); subjects told to discover how to generate rewards. (3)-(5). Training: Subjects were paid (over and above the $8/h flat rate) in proportion to their hit

rates. In the first study (in which active filters passed 8-12 Hz activity, and the rectified, integrated amplitude was utilized), 6 of 8 subjects met learning criteria (a significant difference between baseline and training scores). In the second study (in which on-line FFTs were used to extract alpha power), 3 of 5 subjects met learning criteria.

Saxby, E., & Peniston, E. G. (1995). Alpha-theta brainwave neurofeedback training: an effective treatment for male and female alcoholics with depressive symptoms. *Journal of Clinical Psychology,* 51, 685-693. This was an experimental study of 14 alcoholic outpatients using the Peniston and Kulkosky (1989, 1991) brainwave treatment protocol for alcohol abuse. After temperature biofeedback pretraining, experimental subjects completed 20 40-minute sessions of alpha-theta brainwave neurofeedback training (BWNT). Experimentally treated alcoholics with depressive syndrome showed sharp reductions in self-assessed depression (Beck's Depression Inventory). On the Millon Clinical Multiaxial Inventory-I, the experimental subjects showed significant decreases on the BR scores: schizoid, avoidant, dependent, histrionic, passive-aggression, schizotypal, borderline, anxiety, somatoform, hypomanic, dysthmic, alcohol abuse, drug abuse, psychotic thinking, and psychotic depression. Twenty-one-month follow-up data indicated sustained prevention of relapse in alcoholics who completed BWNT.

Simkin, DR., Thatcher, RW. & Lubar, J. (2014). Quantitative EEGB and Neurofeedback in Children and adolescents: Anxiety disorders, depressive disorders, comorbid addiction and attention-deficit/hyperactivity disorder and brain injury. *Child and Adolescent Psychiatric Clinics of North America*:23(3). 427-464. This article explores the science surrounding neurofeedback. Both surface neurofeedback (using 2-4 electrodes) and newer interventions, such as real-time z-score neurofeedback (electroencephalogram [EEG] biofeedback) and low-resolution electromagnetic tomography neurofeedback, are reviewed. The limited literature on neurofeedback research in children and adolescents is discussed regarding treatment of anxiety, mood, addiction (with comorbid attention-deficit/hyperactivity disorder), and traumatic brain injury. Future potential applications, the use of quantitative EEG for determining which patients will be responsive to medications, the role of randomized controlled studies in neurofeedback research, and sensible clinical guidelines are considered.

Sokhadze, E., Tasman, A., Tamas, R., & El-Mallakh, R. (2011). Event-related potential study of the effects of emotional facial expressions on task performance in euthymic bipolar patients. *Applied Psychophysiology & Biofeedback*, 36(1), 1-13. There appears to be a significant disconnect between symptomatic and functional recovery in

bipolar disorder (BD). Some evidence points to interepisode cognitive dysfunction. We tested the hypothesis that some of this dysfunction was related to emotional reactivity in euthymic bipolar subjects may effect cognitive processing. A modification of emotional gender categorization oddball task was used. The target was gender (probability 25%) of faces with negative, positive, and neutral emotional expression. The experiment had 720 trials (3 blocks × 240 trials each). Each stimulus was presented for 150 ms, and the EEG/ERP responses were recorded for 1,000 ms. The inter-trial interval was varied in 1,100-1,500 ms range to avoid expectancy effects. Task took about 35 min to complete. There were 9 BD and 9 control subjects matched for age and gender. Reaction time (RT) was globally slower in BD subjects. The centro-parietal amplitudes at N170 and N200, and P200 and P300 were generally smaller in the BD group compared to controls. Latency was shorter to neutral and negative targets in BD. Frontal P200 amplitude was higher to emotional negative facial non-targets in BD subjects. The frontal N200 in response to positive facial emotion was less negative in BD subjects. The frontal P300 of BD subjects was lower to emotionally neutral targets. ERP responses to facial emotion in BD subjects varied significantly from normal controls. These variations are consistent with the common depressive symptomology seen in long term studies of bipolar subjects.

Uhlmann, C., & Froscher, W. (2001). Biofeedback treatment in patients with refractory epilepsy: Changes in depression and control orientation. Seizure, 10, 34-38. Depression is a common and serious interictal problem in patients with epilepsy. The genesis of depressive disorders is multifactorial. One aetiological aspect focuses on psychosocial factors. It was hypothesized that uncontrollable, unpredictable chronic aversive events (i.e. epileptic seizures) result in cognitive deficits of external control orientation. If this is true, biofeedback training could represent a possible treatment strategy to lower depression, because biofeedback is known to mediate success experiences and control. Measures of depression and locus of control were administered to 20 patients with refractory partial epilepsy before and after biofeedback treatment. The biofeedback consisted of slow cortical potentials or breathing parameters in 10 patients each. A clear relationship occurred between depression and locus of control in the subjects. After biofeedback training control orientation moved towards a more internal locus of control. Also, depression scores were significantly reduced six months after training. Results show that in patients with refractory epilepsy depression is highly correlated with locus of control, in a way that external control orientation relates to high depression scores. Biofeedback is able to improve internal control orientation through personal success mediation.

Unterrainer, HF., Chen, MJ. & Gruzelier, JH. (2014). EEG-neurofeedback and psychodynamic psychotherapy in a case of adolescent anhedonia with substance misuse: mood:theta relations. International Journal of Psychophysiology:Jul;93(1). 84-95. There is substantial evidence confirming the efficacy of neurofeedback with applications in clinical, educational and optimal performance domains. However, a psychodynamically informed NF-approach needs exploration. A male (19 y), college student whose first year was being seriously compromised after severe, 18-month, polydrug misuse, was treated with 11 sessions including a 2-month follow-up of neurofeedback combined with short-term psychodynamic psychotherapy. Pre/post-treatment and follow-up assessment with the Brief Psychiatric Rating Scale (BPRS) and the Montgomery-Asberg Depression Rating Scale confirmed that levels of psychopathology dropped almost to zero. Correlational evidence disclosed that SMR/theta training was positively associated with reduction in psychopathological ratings, largely due to theta amplitude reduction; the strongest relation being with reduced BPRS activation. Alpha/theta training was not correlated with clinical improvement. The combined treatment was found to be highly effective with the student who learned to deal with feelings of anhedonia and alienation. There was no relapse during the follow-up phase. Further research is recommended.

Walker, J. E., Lawson, R., & Kozlowski, G. (2007). Current status of QEEG and neurofeedback in the treatment of depression. Chapter in J. R. Evans (Ed.), *Handbook of Neurofeedback*. Binghampton, NY: Haworth Medical Press, pp. 341-351. (no abstract available)

EPILEPSY AND SEIZURE DISORDERS

Andrews, D. J., & Schonfeld, W. H. (1992). Predictive factors for controlling seizures using a behavioural approach. *Seizure*, 1(2), 111-116. A behavioural approach using EEG biofeedback for controlling complex-partial seizures has been successful at the Andrews/Reiter Epilepsy Research Program. Records for a random sample of 83 patients with uncontrolled seizures, one third of those receiving care between 1980 and 1985, document that 69 (83%) achieved control by completion of the programme. Additional data about initial age of seizure onset, number of years seizures had been uncontrolled and seizure frequency when treatment started were collected to determine whether these factors predicted seizure control. Only frequency was significantly related to whether seizures were controlled when treatment ended. Further study using discriminant analysis showed that earlier onset age and higher seizure frequency were associated with a significantly greater number of treatment sessions required. Thus, these two factors predicted difficulty in controlling seizures, as measured by number of sessions, although onset age did not predict whether control was eventually achieved. Since even the subgroup achieving the lowest rate of control (i.e., patients having daily seizures when treatment started) had 67% success, these results suggest that a behavioural approach can be useful for many people with currently uncontrolled complex-partial seizures regardless of their characteristics on factors examined in this study.

Cott, A., Pavloski, R. P., & Black, A. H. (1979). Reducing epileptic seizures through operant conditioning of central nervous system activity: Procedural variables. *Science*, 203, 73-75. Operant conditioning of the sensorimotor rhythm of the human electroencephalogram with time-outs contingent on epileptiform activity reduces epileptic seizure rates in patients whose seizures are not well controlled by medication. A comparison of this procedure with time-out training alone demonstrates that operant conditioning of the sensorimotor rhythm is neither necessary nor sufficient for seizure reduction.

Daum, I., Rockstroh, B., Birbaumer, N., Elbert, T., Canavan, A., Lutzenberger, W. (1993). Behavioral treatment of slow cortical potentials in intractable epilepsy: Neuropsychological predictors of outcome. *Journal of Neurosurgery & Psychiatry*, 56 94-97. The study aimed to explore the predictive value of neuropsychological tests within the context of acquisition of slow cortical potential (SCP) self-control, a technique

which has beneficial effects on seizure frequency in epilepsy. Patients with epilepsy who successfully achieved SCP control had longer digit or block-tapping spans than less successful patients. Patients who showed a better learning rate across training also displayed better verbal memory and learning abilities. Seizure reduction was related to block-tapping spans only. The results indicate that measures of attention, as indicated by digit spans or block-tapping spans, offer some predictive value for acquisition of SCP control and treatment outcome, whilst measures of visuospatial or frontal lobe function are unrelated to SCP acquisition and seizure reduction.

Egner T., Sterman MB. (2006). Neurofeedback treatment of epilepsy: from basic rationale to practical application. ***Expert Rev Neurother.*****;6(2):247-57.** The treatment of epilepsy through operant conditioning of the sensorimotor rhythm electroencephalogram has a 35-year history. Neurophysiological studies have shown that this phasic oscillation reflects an inhibitory state of the sensorimotor system. Operant learning of sensory motor rhythm production results in an upregulation of excitation thresholds within the thalamocortical sensory and motor circuitry, which in turn is associated with reduced susceptibility to seizures. The clinical benefits derived from this neurofeedback training protocol, particularly in patients that are nonresponsive to pharmacotherapy, have been documented in many independent laboratories. Recent advances in computer technology have resulted in the availability of relatively inexpensive high-quality equipment for the application of neurofeedback therapy, thus presenting a viable and promising treatment alternative to the interested clinician.

Engel, J., Troupin, A. S., Crandall, P. H., Sterman, M. B., & Wasterlain, C. G. (1982). Recent developments in the diagnosis and therapy of epilepsy. ***Annals of Internal Medicine*****, 97, 584-598.** Recent advances in the diagnosis of epilepsy include the development of a clinically useful classification of epileptic seizures and the recognition of specific epileptic disorders. These advances have been aided by the advent of x-ray computed tomography, long-term electroencephalographic telemetry, and video monitoring. Techniques for functional imaging of the human brain promise even greater diagnostic capabilities. New antiepileptic drugs have improved medical management, and technical and theoretical advances in pharmacokinetics have permitted physicians to design balanced dosing for individual patients. Although currently underused, surgical treatment of partial complex epilepsy can be safe and effective when used appropriately. Operant conditioning of electroencephalography may become another practical alternative therapy. Contributions of basic research to understanding the complications of status

epilepticus have influenced treatment protocols and greatly improved the prognosis of this potentially lethal condition.

Finley, W. W. (1976). Effects of sham-feedback following successful SMR training in an epileptic: A follow-up study. ***Biofeedback & Self-Regulation*****, 1, 227-235.** After 1 year of SMR biofeedback training of a severe epileptic teenage male, incidence of atonic seizures decreased from 8/hr to less than 1/3 hr. SMR increased from 10% to 70%. Epileptiform discharges decreased from 45% to 15%. Unknown to the patient, his family, or certain members of our research staff, noncontingent feedback was introduced on 7/22/74, ending 9/11/74. A significant decrease occurred for SMR (down 8%), and a significant increase for epileptiform discharges (up 4%). Rate of seizures increased, but was not statistically significant over preceding months of contingent feedback. Incidence of seizures associated with urine loss increased from approximately 6/month to 23/month during noncontingent feedback, a significant increase. Urine-loss results suggest that although seizures did not become more frequent, those the patient did experience were "harder," i.e., more severe. Contingent feedback was reinstituted following the 7-wk sham, and recovery of all variables to their former levels (prior to sham) occurred.

Finley, W. W. (1977). Operant conditioning of the EEG in two patients with epilepsy: Methodologic and clinical considerations. ***Pavlovian Journal of Biological Science*****, 12(2), 93-111.** Methodologic and clinical considerations are discussed in sensorimotor rhythm (SMR) biofeedback research on two dissimilar but severe epileptic males. The first case, an akinetic epileptic who prior to feedback training experienced 80-100 clinical seizures every 10 hours, showed considerable seizure reduction after 6 months of SMR and epileptiform training. A number of methodologic and instrumentation advances were pioneered with the akinetic patient: (1) development of and ultra-sharp band-pass filter; (2) use of epileptiform inhibit and feedback circuitry; (3) use of monetary rewards as additional incentive; (4) use of correlational analysis for evaluation of acquisition in the major dependent variables and; (5) use of noncontingent feedback and reinforcement as control techniques. The second case, a psychomotor epileptic, also showed therapeutic benefit from SMR training. Clinical information regarding the effect of anticonvulsant medications on the course and therapeutic outcome of SMR training are described. In conjunction with operant conditioning of 12 Hz activity, corresponding changes for other EEG parameters are examined.

Finley, W. W., Smith, H. A., & Etherton, M. D. (1975). Reduction of seizures and normalization of the EEG in a severe epileptic following sensorimotor biofeedback training: Preliminary study. ***Biological Psychiatry*****, 2, 189-203.** Sensorimotor rhythm

(SMR) biofeedback training was attempted in a 13-year-old male with frequent epileptic seizures. Prior to training the subject was averaging almost eight clinical seizures an hour. The SMR filter was tuned sharply to 12 plus or minus 1 Hz. Feedback was conducted over approximately six months and continues to the present. In that time the subject's percentage of SMR increased from about 10%, prior to training, to 65% after the 34th training session. Correspondingly, his rate of clinical seizures decreased by a factor of 10 and a significant reduction in percentage of epileptiform discharges was noted. Beginning with trial 35, the subject was provided feedback of epileptiform activity in combination with 12 Hz activity. The combined effect of these two treatment variables was to reduce the trial-to-trial variance in the dependent variables of interest.

Hanson, L. M., Trudeau, D. L., & Grace, D. L. (1996). Neurotherapy and drug therapy in combination for adult ADHD, personality disorder, and seizure disorder: A case report. *Journal of Neurotherapy*, 2(1) 6-14. This is a case report of an adult female patient with ADHD, temporal seizure disorder, and Borderline Personality Disorder treated with 30 weekly sessions of SMR neurofeedback and carbamazepine. Post-treatment measures showed improvements in T.O.V.A., self report, and QEEG. Both neurofeedback and carbamazepine showed the most effect in early treatment. Progress continued after discontinuance of the drug.

Hurt, E., Arnold, AE. & Lofthouse, N. (2014). Quantitative EEG neurofeedback for the treatment of pediatric attention-deficit hyperactivity disorder, autism spectrum disorders, learning disorders and epilepsy. Child and Adolescent Psychiatric Clinics of North America:23(3). 465-86. Neurofeedback (NF) using surface electroencephalographic signals has been used to treat various child psychiatric disorders by providing patients with video/audio information about their brain's electrical activity in real-time. Research data are reviewed and clinical recommendations are made regarding NF treatment of youth with attention deficit/hyperactivity disorder, autism, learning disorders, and epilepsy. Most NF studies are limited by methodological issues, such as failure to use or test the validity of a full-blind or sham NF. The safety of NF treatment has not been thoroughly investigated in youth or adults, although clinical experience suggests reasonable safety.

Kaplan, B. J. (1975). Biofeedback in epileptics: Equivocal relationship of reinforced EEG frequency to seizure reduction. *Epilepsia*, 16, 477-485. It has been reported that biofeedback training of 12- to 14-Hz activity recorded over Rolandic cortex was accompanied by a reduction in seizure incidence in four human epileptics (Sterman et al., 1974). Biofeedback training of 12- to 14-Hz activity was provided for two epileptics and had no effect on clinical EEGs, seizure incidence, or proportion of EEG spectral

power in the frequency range being trained. Subsequently, biofeedback training of 6- to 12-Hz Rolandic activity was provided for three epileptics. Two patients experienced reductions in seizure not accompanied by medication changes. Since no learning of 6- to 12-Hz activity was detected, the changes in seizure incidence are not attributed to EEG biofeedback. It is suggested that the experience in the feedback setting provided these two patients with new techniques of relaxation. In view of the lack of statistical evidence of EEG changes following EEG biofeedback and the small number of patients trained to date, it appears wise to maintain a cautious attitude until the issue of causality is clear.

Kotchoubey, B., Busch, S., Strehl, U., & Birbaumer, N. (1999). Changes in EEG power spectra during biofeedback of slow cortical potentials in epilepsy. *Applied Psychophysiology & Biofeedback*, 24(4), 213-233. The goal of the study was to explore parallel changes in EEG spectral frequencies during biofeedback of slow cortical potentials (SCPs) in epilepsy patients. Thirty-four patients with intractable focal epilepsy participated in 35 sessions of SCP self-regulation training. The spectral analysis was carried out for the EEG recorded at the same electrode site (Cz) that was used for SCP feedback. The most prominent effect was the increase in the theta 2 power (6.0-7.9 Hz) and the relative power decrement in all other frequency bands (particularly delta 1, alpha 2 and beta 2) in transfer trials (i.e., where patients controlled their SCPs without continuous feedback) compared with feedback trials. In the second half of the training course (i.e., sessions 21-35) larger power values in the delta, theta, and alpha bands were found when patients were required to produce positive versus negative SCP shifts. Both across-subject and across-session (within-subject) correlations between spectral EEG parameters, on the one hand, and SCP data, on the other hand, were low and inconsistent, contrary to high and stable correlations between different spectral variables. This fact, as well as the lack of considerable task-dependent effects during the first part of training, indicates that learned SCP shifts did not directly lead to the specific dynamics of the EEG power spectra. Rather, these dynamics were related to nonspecific changes in patients' brain state.

Kotchoubey, B., Strehl, U., Uhlmann, C., Holzapfel, S., Konig, M., Froscher, W., Blankenhorn, V., & Birbaumer, N. (2001). Modification of slow cortical potentials in patients with refractory epilepsy: A controlled outcome study. *Epilepsia*, 42(3), 406-416. The goal of the study was to explore parallel changes in EEG spectral frequencies during biofeedback of slow cortical potentials (SCPs) in epilepsy patients. Thirty-four patients with intractable focal epilepsy participated in 35 sessions of SCP self-regulation

training. The spectral analysis was carried out for the EEG recorded at the same electrode site (Cz) that was used for SCP feedback. The most prominent effect was the increase in the theta 2 power (6.0-7.9 Hz) and the relative power decrement in all other frequency bands (particularly delta 1, alpha 2 and beta 2) in transfer trials (i.e., where patients controlled their SCPs without continuous feedback) compared with feedback trials. In the second half of the training course (i.e., sessions 21-35) larger power values in the delta, theta, and alpha bands were found when patients were required to produce positive versus negative SCP shifts. Both across-subject and across-session (within-subject) correlations between spectral EEG parameters, on the one hand, and SCP data, on the other hand, were low and inconsistent, contrary to high and stable correlations between different spectral variables. This fact, as well as the lack of considerable task-dependent effects during the first part of training, indicates that learned SCP shifts did not directly lead to the specific dynamics of the EEG power spectra. Rather, these dynamics were related to nonspecific changes in patients' brain state.

Kuhlman, W. N. (1978). EEG feedback training of epileptic patients: Clinical and electroencephalographic analysis. ***Electroencephalography & Clinical Neurophysiology*****, 45(6), 699-710.** To evaluate the clinical efficacy and mechanisms underlying EEG feedback training of epileptic patients, 5 adult patients with poorly controlled seizures were studied for 4--10 months during which quantitative analysis of seizures, the EEG, and serum anticonvulsant levels was conducted. Sustained seizure reduction did not occur during the first 4--5 weeks in which feedback signals were presented randomly in relation to the EEG. When feedback was then made contingent upon central 9--14 c/sec activity, seizures declined by 60% in 3 patients. Power spectral analysis showed upward shifts in EEG frequency, decreases in abnormal slow activity, and enhancement of alpha rhythm activity as a function of contingent training, but no specific EEG change was associated with seizure reduction in all patients. No evidence was obtained for the hypothesized involvement of a 'sensorimotor rhythm' or motor inhibition in the training effects. The lack of effect in two patients could not be attributed to insufficient training, lack of motivation, or to differences in seizure classification. A second phase of research showed that continued laboratory training was both sufficient and necessary for maintaining clinical and EEG effects. Results indicate that: (1) significant seizure reductions can occur with EEG feedback training which are not related to placebo effects, non-specific factors or to changes in medication; (2) EEG changes associated with such training can best be described as 'normalization'; (3) continued clinical

investigation of EEG feedback training as a non-pharmacological adjunct to conventional therapy appears justified.

Kuhlman, W. N., & Allison, T. (1977). EEG feedback training in the treatment of epilepsy: Some questions and some answers. ***Pavlovian Journal of Biological Science*****, 12(2), 112-122.** A basic question in EEG feedback training of epileptic patients is whether the decrease in seizures is specifically due to the training or to other factors. Questions may also be raised as to what EEG changes are involved. Preliminary results in five patients suggest that seizure reductions can occur with training which are not due to placebo or nonspecific effects or to changes in medication compliance. These changes occurred rapidly during EEG-contingent feedback training but not when feedback was random in relation to the EEG. Reliable changes in the EEG were also observed, but the question of which mechanism accounts for these results has yet to be answered.

Lantz, D., & Sterman, M. B. (1988). Neuropsychological assessment of subjects with uncontrolled epilepsy: Effects of EEG biofeedback training. ***Epilepsia*****, 29(2), 163-171.** A battery of neuropsychological tests was administered at baseline, post-control period, and post-training period to 24 drug-refractory subjects with epilepsy participating in a study of sensorimotor electroencephalographic (EEG) normalization feedback training. Results revealed the following. First, subjects exhibited significant baseline deficits in psychosocial, cognitive and motor functioning. Second, certain tests discriminated subjects before training who were subsequently above and below the median in seizure reduction following EEG training. Subjects who showed the greatest seizure reduction performed better on a test of general problem-solving ability but not on other cognitive tests and worse on tests involving strong motor components and were more intact psychosocially. These subjects also took significantly fewer medications in combination than did less successful subjects. Third, improvement on several measures occurred following participation in the study. Cognitive and motor functioning improved only in subjects with the greatest seizure reduction and only after actual training as opposed to control conditions. Psychological functioning, as measured by the Minnesota Multiphasic Personality Inventory (MMPI) improved in both outcome groups. MMPI improvement, unlike cognitive improvement, was as likely to occur after control conditions, when seizure reduction had not yet occurred, as after EEG training. Thus, MMPI changes apparently reflected the nonspecific benefits of participation in this study.

Legarda SB, McMahon D, Othmer S, Othmer S. (2011). Clinical neurofeedback: Case studies, proposed mechanism, and implications for pediatric neurology practice. ***J***

Child Neurol. **2011 Aug;26(8):1045-51**. Trends in alternative medicine use by American health care consumers are rising substantially. Extensive literature exists reporting on the effectiveness of neurofeedback in the treatment of autism, closed head injury, insomnia, migraine, depression, attention deficit hyperactivity disorder, epilepsy, and posttraumatic stress disorder. We speculated that neurofeedback might serve as a therapeutic modality for patients with medically refractory neurological disorders and have begun referring patients to train with clinical neurofeedback practitioners. The modality is not always covered by insurance. Confident their child's medical and neurological needs would continue to be met, the parents of 3 children with epilepsy spectrum disorder decided to have their child train in the modality. The children's individual progress following neurofeedback are each presented here. A proposed mechanism and practice implications are discussed.

Lubar, J. F., & Bahler, W. W. (1976). Behavioral management of epileptic seizures following EEG biofeedback training of the sensorimotor rhythm. ***Biofeedback & Self-Regulation,*** **7, 77-104.** Eight severely epileptic patients, four males and four females, ranging in age from 10 to 29 years, were trained to increase 12-14 Hzeta EEG activity from the regions overlying the Rolandic area. This activity, the sensorimotor rhythm (SMR), has been hypothesized to be related to motor inhibitory processes (Sterman, 1974). The patients represented a cross-section of several different types of epilepsy, including grand mal, myoclonic, akinetic, focal, and psychomotor types. Three of them had varying degrees of mental retardation. SMR was detected by a combination of an analog filtering system and digital processing. Feedback, both auditory and/or visual, was provided whenever one-half second of 12-14-Hz activity was detected in the EEG. Patients were provided with additional feedback keyed by the output of a 4-7-Hz filter which indicated the presence of epileptiform spike activity, slow waves, or movement. Feedback for SMR was inhibited whenever slow-wave activity spikes or movement was also present. During the treatment period most of the patients showed varying degrees of improvement. Two of the patients who had been severely epileptic, having multiple seizures per week, have been seizure free for periods of up to 1 month. Other patients have developed the ability to block many of their seizures. Seizure intensity and duration have also decreased. Furthermore, the successful patients demonstrated an increase in the amount of SMR and an increase in amplitude of SMR during the training period. Spectral analyses for the EEGs were performed periodically. The effectiveness of SMR conditioning for the control of epileptic seizures is evaluated in terms of patient characteristics and type of seizures.

Lubar, J. F., Shabsin, H. S., Natelson, S. E. et al. (1981). EEG operant conditioning in intractable epileptics. *Archives of Neurology*, 38, 700-704. Eight epileptic patients with mixed seizures refractory to medical control participated in a double-blind crossover study to determine the effectiveness of operant conditioning of the EEG as an anticonvulsant procedure. Baseline levels of seizures were recorded for four months prior to the beginning of treatment. Participants then received false (noncontingent) feedback for two months followed by an ABA-patterned training program lasting a total of ten months. Subjects were assigned to three treatment groups based on different schedules of EEG feedback. They were first trained (A1 phase) either to suppress slow activity (3 to 8 Hz), to enhance 12- to 15-Hz activity, or to simultaneously suppress 3- to 8-Hz and enhance 11- to 19-Hz activity. This was followed by a B phase, in which patients were trained to enhance slow activity (3 to 8 Hz). In the final phase (A2), the initial training contingencies were reinstated. Neuropsychological tests were performed before and after training, and changes in EEG activity as determined by Fast Fourier spectral analyses were analyzed. Five of eight patients experienced a decrease in their mean monthly seizure rate at the completion of feedback training as compared with their initial baseline level.

Monderer, R. S., Harrison, D. M., & Haut, S. R. (2002). Review: Neurofeedback and epilepsy. *Epilepsy & Behavior*, 3, 214-218. Over the past three decades, researchers have examined various behavioral approaches to the treatment of epilepsy. One prominent line of inquiry concerns the effectiveness of neurofeedback, which entails the entrainment of specific electroencephalographic frequencies for the purpose of decreasing seizure frequencies in patients with epilepsy. This article reviews the current literature on the efficacy of neurofeedback in reducing seizure frequency. While it is clear that neurofeedback had a positive effect in most of the studies reviewed, these findings are limited due to multiple confounding factors. In the absence of any rigorously controlled studies, the relationship between neurofeedback and seizure frequency cannot be firmly established. Despite these limitations, the promising role of neurofeedback as a treatment for epilepsy is illustrated.

Nagai, Y. (2014). Biofeedback treatment for epilepsy. Nihon Rinsho: May:7(5). 887-893. Pharmacological treatment is the mainstay for the treatment of epilepsy. However concerns regarding long-term side effects of drugs are increasingly voiced. Behavioral treatments including biofeedback, represents an alternative management option for the control of epilepsy. Biofeedback is a non-invasive bio-behavioral procedure through which patients can learn to gain psychophysiological control over seizures. This article

will first overview seizure precipitation from a psychological perspective, and then introduce three major biofeedback treatments. Sensory motor rhythm (SMR) and slow cortical potential(SCP) biofeedback uses electroencephalographic parameters and are categorized as neurofeedback. Electrodermal activity (EDA) biofeedback focuses on modulation of peripheral sympathetic tone. The neural mechanisms underlying biofeedback treatment will be discussed in relation to thalamo-cortical regulation (of neural excitability across brain networks).

Nagai Y, Matsuura M. (2011). Biofeedback for Epilepsy. *Brain Nerve*. 2011 Apr;63(4):385-92. Anti-epileptic drugs are the mainstay in the management of epilepsy. However, approximately 30% of patients continue to have seizures despite optimal drug therapy. Behavioural interventions that include biofeedback have become increasingly popular over the last 3 decades, and the results have mostly been encouraging. Biofeedback is a non-invasive behavioural treatment that enables a patient to gain volitional control over a physiological process. In epilepsy, targeted parameters for biofeedback include electroencephalographic (EEG) measures of cortical activity, such as different EEG frequencies or cortical potentials (i.e., neurofeedback), and peripheral autonomic activity, such as Galvanic Skin Response (GSR). In this review, biofeedback using Sensory Motor Rhythm (SMR), Slow Cortical Potentials (SCP), and GSR are discussed. SMR biofeedback was established in the 1970s and is the most prominent methodology for biofeedback treatment of epilepsy in published literature. The technique is now regaining its popularity. SCP biofeedback was introduced in the 1990s. In contrast to SMR biofeedback, which modulates the frequency components of EEG, SCP biofeedback focuses on the regulation of potential changes (amplitude of DC shift). The clinical trials conducted using SCP biofeedback were larger than those conducted using SMR biofeedback, and their overall outcomes were promising. GSR biofeedback is a relatively new methodology in its application to epilepsy and focuses on the modulation of electrodermal measures of sympathetic activity. Compared to the neurofeedback approach, GSR biofeedback is much easier to implement, and evidence suggests that its clinical benefits can be achieved more rapidly. Although the biofeedback treatment may never achieve the status of an alternative to pharmacotherapy for epilepsy, current research findings strongly suggest that biofeedback has the potential to become a potent adjunctive non-pharmacological approach to reduce seizure frequency in patient with drug-resistant epilepsy. Further research, especially a well-controlled large clinical trial, is necessary and anticipated.

Osterhagen L, Breteler M, van Luijtelaar G. (2010). Does arousal interfere with operant conditioning of spike-wave discharges in genetic epileptic rats? *Epilepsy Res*. 2010 Jun;90(1-2):75-82. One of the ways in which brain computer interfaces can be used is neurofeedback (NF). Subjects use their brain activation to control an external device, and with this technique it is also possible to learn to control aspects of the brain activity by operant conditioning. Beneficial effects of NF training on seizure occurrence have been described in epileptic patients. Little research has been done about differentiating NF effectiveness by type of epilepsy, particularly, whether idiopathic generalized seizures are susceptible to NF. In this experiment, seizures that manifest themselves as spike-wave discharges (SWDs) in the EEG were reinforced during 10 sessions in 6 rats of the WAG/Rij strain, an animal model for absence epilepsy. EEG's were recorded before and after the training sessions. Reinforcing SWDs let to decreased SWD occurrences during training; however, the changes during training were not persistent in the post-training sessions. Because behavioural states are known to have an influence on the occurrence of SWDs, it is proposed that the reinforcement situation increased arousal which resulted in fewer SWDs. Additional tests supported this hypothesis. The outcomes have implications for the possibility to train SWDs with operant learning techniques.

Quy, R. J., Hutt, S. J., & Forrest, S. (1979). Sensorimotor rhythm feedback training and epilepsy: Some methodological and conceptual issues. *Biological Psychology*, 9, 129-149. This study examined the hypothesis that the enhancement of a 12-16 Hz sensorimotor rhythm in the EEG is inhibitory to epileptic seizure activity. The effects of training to enhance 12-16 Hz central EEG, to enhance 8-10 Hz central EEG, to suppress high voltage EEG activity, and of random feedback were compared over a period of 12 months in three adult patients suffering from chronic, drug-refractory epilepsy. All three patients experienced a significant reduction in seizure rate by the end of the study, but this was not related to any one particular training condition. It is suggested that the therapeutic mechanism might involve placebo effects, relaxation training, or a facilitation of EEG desynchronization, the effect being idiosyncratic to the individual patient.

Rockstroh, B., Elbert, T., Birbaumer, N., Wolf, P., Duchting-Roth, A., Reker, M., Daum, I., Lutzenberger, W., & Dichgans, J. (1993). Cortical self-regulation in patients with epilepsies. *Epilepsy Research*, 14. 63-72. The present study aimed at investigating to what extent the regulation of excitability in cortical networks, as indicated by surface-negative slow cortical potentials (SCPs), is impaired in epileptic patients and to what

extent training of SCP self-regulation by means of biofeedback and instrumental learning procedures might affect seizure frequency. Twenty-five patients suffering from drug-refractory epilepsies (complex focal, grand mal, and absence type of seizures) participated in 28 1-h sessions of feedback and instrumental conditioning of their SCPs. Subjects' EEGs were obtained from the vertex. Depending on discriminative stimuli DC shifts towards increased or suppressed negativity relative to the pre-trial baseline were demonstrated by on-line visual feedback during intervals of 8 s each; each session comprised 110 trials. While performance on the SCP self-regulation task was initially below normal (as compared to healthy subjects), significant increases in SCP control were achieved by the patients across the 28 training sessions. In 18 patients at least 1-year follow-up data are available. Changes in seizure frequency were related to transfer of SCP control with six of the patients becoming seizure-free. Age affected the ability to acquire SCP control and its impact on seizure frequency.

Seifert, A. R.,& Lubar, J. F. (1975). Reduction of epileptic seizures through EEG biofeedback training. *Biological Psychology*, 3, 157-184. Biofeedback training of the sensorimotor rhythm (SMR) was carried out in three male and three female adolescent epileptics and in two normal controls. The patients represented a cross-section of epilepsies including grand mal, myoclonic, afocal and psychomotor types. Three of the cases were mentally retarded. 12-14 Hz (SMR) activity was detected by a combination of sharp analog filtering and digital processing. The patients were provided with feedback whenever they produced 0.5 sec of 12-14 Hz activity of a specified amplitude. Additional feedback was provided for epileptiform activity slow waves or movement. Furthermore, feedback for SMR production was inhibited by digital logic circuitry when movement, slow waves or spikes were present. Seizure reduction was obtained in five of the six epileptics. Several patients showed increased percentage of SMR when feedback was provided and varying degrees of normalization in their EEG as demonstrated by fast Fourier, crossed power spectral density and coherence analyses.

Sterman, M. B. (2000). Basic concepts and clinical findings in the treatment of seizure disorders with EEG operant conditioning. *Clinical Electroencephalography*, 31(1), 45-55. Two issues concerning sensorimotor EEG operant conditioning, or biofeedback, as a therapeutic modality for the treatment of seizure disorders are the focus of this review. The first relates to the question of whether relevant physiological changes are associated with this procedure. This question is addressed through review of an extensive neurophysiological literature that is likely unfamiliar to many clinicians but that documents both immediate and sustained functional changes that are consistent

with elevation of seizure thresholds. The second focuses on the clinical efficacy of this method and whether it should carry the designation of "experimental". This designation is challenged through an assessment of over 25 years of peer-reviewed research demonstrating impressive EEG and clinical results achieved with the most difficult subset of seizure patients.

Sterman, M. B. (1977). ***Effects of sensorimotor EEG feedback on sleep and clinical manifestations of epilepsy*****. Chapter in J. Beatty & H. Legewie (Eds.), Biofeedback and Behavior. New York: Plenum, pp. 167-200.**

Sterman, M. B. (1977). Sensorimotor EEG operant conditioning: Experimental and clinical effects. ***Pavlovian Journal of Biological Sciences*****, 12(2), 63-92.** no abstract.

Sterman, M. B. (1973). Neurophysiological and clinical studies of sensorimotor EEG biofeedback training: Some effects on epilepsy. ***Seminars in Psychiatry*****, 5(4), 507-525**. No abstract.

Sterman MB, Egner T. (2006). Foundation and practice of neurofeedback for the treatment of epilepsy. ***Appl Psychophysiology & Biofeedback.*** **2006 Mar;31(1):21-35.** This review provides an updated overview of the neurophysiological rationale, basic and clinical research literature, and current methods of practice pertaining to clinical neurofeedback. It is based on documented findings, rational theory, and the research and clinical experience of the authors. While considering general issues of physiology, learning principles, and methodology, it focuses on the treatment of epilepsy with sensorimotor rhythm (SMR) training, arguably the best established clinical application of EEG operant conditioning. The basic research literature provides ample data to support a very detailed model of the neural generation of SMR, as well as the most likely candidate mechanism underlying its efficacy in clinical treatment. Further, while more controlled clinical trials would be desirable, a respectable literature supports the clinical utility of this alternative treatment for epilepsy. However, the skilled practice of clinical neurofeedback requires a solid understanding of the neurophysiology underlying EEG oscillation, operant learning principles and mechanisms, as well as an in-depth appreciation of the ins and outs of the various hardware/software equipment options open to the practitioner. It is suggested that the best clinical practice includes the systematic mapping of quantitative multi-electrode EEG measures against a normative database before and after treatment to guide the choice of treatment strategy and document progress towards EEG normalization. We conclude that the research literature reviewed in this article justifies the assertion that neurofeedback treatment of

epilepsy/seizure disorders constitutes a well-founded and viable alternative to anticonvulsant pharmacotherapy.

Sterman, M. B., Macdonald, L. R., & Stone, R. K. (1974). Biofeedback training of the sensorimotor electroencephalogram rhythm in man: Effects on epilepsy. *Epilepsia*, 15(3), 395-416. No abstract.

Sterman, M. B., & Macdonald, L. R. (1978). Effects of central cortical EEG feedback training on incidence of poorly controlled seizures. *Epilepsia*, 19(3), 207-222. This study examined the clinical effects of central cortical EEG feedback training in 8 patients with poorly controlled seizures. After base-line recordings, patients were trained in the laboratory and then initiated on a double or triple crossover design using portable equipment at home, with bimonthly laboratory test sessions. Performance at home was monitored by a strip chart recorder with the portable unit. Training was based on the simultaneous detection of two central cortical (C3--T3) EEG frequency bands (6--9 Hz and either 12--15 or 18--23 Hz), with reward provided for the occurrence of one in the absence of the other. The design consisted of successive 3 month periods of training, with reward contingencies reversed after each period without the subject's knowledge. Seizure incidence records were compared statistically before, during, and after the design. Six of the 8 patients reported significant and sustained seizure reductions, which averaged 74%, following reward for either 12--15 or 18--23 Hz in the absence of 6--9 Hz. Response to positive reward for 12--15 Hz was specific, with seizure rates returning to base line when reinforcement contingencies were reversed. Reduced seizure rates following positive reward for 18--23 Hz were not altered with contingency reversals. A nonspecific interpretation of these effects is rejected in favor of an EEG normalizing hypothesis.

Sterman, M. B., & Shouse, M. N. (1980). Quantitative analysis of training, sleep EEG and clinical response to EEG operant conditioning in epileptics. *Electroencephalography & Clinical Neurophysiology*, 49, 558-576. This report is a follow-up to a previous paper which described seizure rate changes with central cortical EEG feedback training in 8 poorly controlled epileptic subjects. Data examined here include associated training compliance and performance, sleep EEG spectra, clinical EEG and anticonvulsant blood levels. The study employed a double-cross-over, single blind ABA design applied to two subgroups of epileptic patients. Both groups had in common two training periods (A1, A2) in which either 12--15 c/sec (subgroup I, n = 4) or 18--23 c/sec (subgroup II, n = 4) was reinforced in the absence of 6--9 c/sec, movement or epileptiform discharge, and one training period (B) in which 6--9 c/sec was

reinforced in the absence of 12--15 or 18--23 c/sec as well as movement and epileptiform discharge. Training periods occurred primarily in the home and lasted 3 months. Compliance with training instructions and response acquisition were demonstrated. Overall anticonvulsant blood levels were low and unrelated to EEG or seizure changes. Clinical EEG findings corresponded to sleep EEG and seizure rate outcomes. Power spectral analysis of sampled non-REM sleep from all-night EEG recordings obtained after each training phase indicated contingency specific changes which were limited to sensorimotor recordings in subgroup I and corresponded to the pattern of seizure rate changes in this group. EEG changes were also limited to sensorimotor cortex in subgroup II, but were linear and paralleled a progressive decrease in seizure rate. Both groups, however, showed the same pattern of EEG changes with seizure reductions; low and high frequencies were reduced and intermediate, rhythmic frequencies increased. Correlational analysis confirmed this relationship. The pattern, duration and topographic specificity of these changes suggested a normalization of sensorimotor EEG substrates related to the EEG feedback training.

Strehl, U., Birkle, SM., Worz, S. & Kotchoubey, B. (2014). Sustained reduction of seizures in patients with intractable epilepsy after self-regulation training of slow cortical potentials - 10 years after. Front Hum Neurosci. 2014 Aug 8;8:604. The aim of this study was to determine whether the reduction of seizures in patients with intractable epilepsy after self-regulation of slow cortical potentials (SCPs) was maintained almost 10 years after the end of treatment. Originally, 41 patients received training with SCP-neurofeedback. A control group of 12 patients received respiratory feedback while another group of 11 patients had their anticonvulsant medications reviewed. Nineteen patients in the experimental group participated at least in parts of the long-term follow-up, but only two patients from each control group agreed to do so. The follow-up participants completed the same seizure diaries as in the original study. Patients of the experimental group also took part in three SCP-training sessions at the follow-up evaluation. Due to the small sample size, the results of participants in the control groups were not considered in the analysis. A significant decrease in seizure frequency was found about 10 years after the end of SCP treatment. The clinical significance of this result is considered medium to high. All patients were still able to self-regulate their SCPs during the feedback condition. This success was achieved without booster sessions. This is the longest follow-up evaluation of the outcome of a psychophysiological treatment in patients with epilepsy ever reported. Reduced seizure frequency may be the result of patients continued ability to self-regulate their SCPs.

Given such a long follow-up period, the possible impact of confounding variables should be taken into account. The small number of patients participating in this follow-up evaluation diminishes the ability to make causal inferences. However, the consistency and duration of improvement for patients who received SCP-feedback training suggests that such treatment may be considered as a treatment for patients with intractable epilepsy and as an adjunct to conventional therapies.

Strehl, U., Trevorrow, T., Veit, R., Hinterberger, T., Kotchoubey, B., Erb, M., & Birbaumer, N. (2006). Deactivation of brain areas during self-regulation of slow cortical potentials in seizure patients. Applied Psychophysiology & Biofeedback, 31(1), 85-94. This study investigates the neurophysiological basis of EEG feedback for patients with epilepsy. Brain areas are identified that become hemodynamically deactivated when epilepsy patients, trained in EEG self-regulation, generate positive slow cortical potentials (SCPs). Five patients were trained in producing positive SCPs, using a training protocol previously established to reduce seizure frequency in patients with drug refractory epilepsy. Patients attempted to produce positive SCP shifts in a functional magnetic resonance imaging (fMRI) scanner. Two patients were able to reliably produce positive SCP shifts. When these successful regulators were prompted to produce positive SCPs, blood oxygen level-dependent (BOLD) response indicated deactivation, in comparison to a control state, around the recording electrode, frontal lobe, and thalamus. Unsuccessful regulators' BOLD response indicated no deactivation in cortical areas proximal to the active electrode. No thalamic deactivation was found in poor regulators. Decreased seizure frequency from SCP training may be the result of positively reinforced inhibition in cortical areas proximal to active electrode placement, the frontal cortex, and the thalamus.

Swingle, P. G. (1998). Neurofeedback treatment of pseudo seizure disorder. *Biological Psychiatry*, 44(11), 1-4. BACKGROUND: Previous research has shown that the suppression of theta wave activity and the enhancement of sensorimotor rhythm (SMR) through electroencephalographic (EEG) biofeedback is an effective treatment for epilepsy. The current research reports the results of EEG biofeedback treatment for patients presenting with seizure behaviors in the absence of eliptiform EEG activity. METHODS: In addition to psychotherapy, 3 patients, 2 women and 1 man, were trained, using EEG feedback once per week, to reduce the ratio of theta band to SMR band EEG amplitudes. RESULTS: The results showed that reductions in seizure activity were related to reductions in the theta-SMR ratio. CONCLUSIONS: These findings support the

view that theta-SMR feedback training, in conjunction with psychotherapy, is an effective adjunctive treatment for pseudoseizure disorder.

Tan, G., Thornby, J., Hammond, D. C., Strehl, U., Canady, B., Arnemann, K., & Kaiser, D. K. (2009). Meta-analysis of EEG biofeedback in treating epilepsy. ***Clinical EEG & Neuroscience*****, 40(3), 173-179.** About one third of patients with epilepsy do not benefit from medical treatment. For these patients electroencephalographic (EEG) biofeedback is a viable alternative. EEG biofeedback, or neurofeedback, normalizes or enhances EEG activity by means of operant conditioning. While dozens of scientific reports have been published on neurofeedback for seizure disorder, most have been case series with too few subjects to establish efficacy. The purpose of this paper is to meta-analyze existing research on neurofeedback and epilepsy. We analyzed every EEG biofeedback study indexed in MedLine, PsychInfo, and PsychLit databases between 1970 and 2005 on epilepsy that provided seizure frequency change in response to feedback. Sixty-three studies have been published, 10 of which provided enough outcome information to be included in a meta-analysis. All studies consisted of patients whose seizures were not controlled by medical therapies, which is a very important factor to keep in mind when interpreting the results. Nine of 10 studies reinforced sensorimotor rhythms (SMR) while 1 study trained slow cortical potentials (SCP). All studies reported an overall mean decreased seizure incidence following treatment and 64 out of 87 patients (74%) reported fewer weekly seizures in response to EEG biofeedback. Treatment effect was mean log (post/pre) where pre and post represent number of seizures per week prior to treatment and at final evaluation, respectively. Due to prevalence of small groups, Hedges's g was computed for effect size. As sample heterogeneity was possible (Q test, p=.18), random effects were assumed and the effect of intervention was -0.233, SE = 0.057, z = -4.11, p<.001. Based on this meta-analysis, EEG operant conditioning was found to produce a significant reduction on seizure frequency. This finding is especially noteworthy given the patient group, individuals who had been unable to control their seizures with medical treatment.

Tansey, M. A. (1985). The response of a case of petit mal epilepsy to EEG sensorimotor rhythm biofeedback training. ***International Journal of Psychophysiology*****, 3, 81-84.** A 14-year-old girl, with a long history of absence seizures, sudden rages, spatial disorientation, and academic difficulties received long-term (33 sessions) EEG sensorimotor rhythm biofeedback training. Operantly conditioned increases in the average amplitude of the 14 Hz neural discharge rhythm, over the central Rolandic cortex and cerebrolongitudinal fissure, resulted in a total cessation of her absence seizures; which

had, prior to the EEG sensorimotor rhythm biofeedback training, occurred at the rate of 4-5 absences per hour. Concurrently, her sudden rages, spatial disorientation, and academic functioning all evidenced significant remediation.

Tozzo, C.A., Elfner, L. F., & May Jr., J. G. (1988). Biofeedback and relaxation training in the control of epileptic seizures. ***International Journal of Psychophysiology*****, 6, 185-194.** Research utilizing sensorimotor rhythm (SMR) biofeedback with epileptics suggests that it is useful in decreasing seizures. Subjects were 6 young adults with a diagnosis of epilepsy of at least two years who had been unable to control their seizures with different regimens of anticonvulsant medications. Subjects ranged from severely mentally handicapped to above average functioning. Seizure type, frequency, and duration were recorded by subjects and caretakers. Measures of operant learning were percent time in SMR. The experiment utilized a single subject multiple baseline design which consisted of 6 phases: baseline one, relaxation training; baseline two, biofeedback training one; baseline three, biofeedback treatment two and follow-up. The results of this study are in agreement with other studies using SMR biofeedback. All subjects were able to significantly increase percent time in SMR. Five out of the 6 subjects demonstrated decreases in seizure frequency during the treatment phase. Two of the 6 subjects benefited from relaxation training. Four subjects demonstrated significant negative correlations between percent SMR and seizure rats. Consistent with other studies utilizing multiple baseline designs, a majority of the subjects did not follow the design of the study.

Uhlmann, C., & Froscher, W. (2001). Biofeedback treatment in patients with refractory epilepsy: Changes in depression and control orientation. ***Seizure*****, 10(1), 34-38.** Depression is a common and serious interictal problem in patients with epilepsy. The genesis of depressive disorders is multifactorial. One aetiological aspect focuses on psychosocial factors. It was hypothesized that uncontrollable, unpredictable chronic aversive events (i.e. epileptic seizures) result in cognitive deficits of external control orientation. If this is true, biofeedback training could represent a possible treatment strategy to lower depression, because biofeedback is known to mediate success experiences and control. Measures of depression and locus of control were administered to 20 patients with refractory partial epilepsy before and after biofeedback treatment. The biofeedback consisted of slow cortical potentials or breathing parameters in 10 patients each. A clear relationship occurred between depression and locus of control in the subjects. After biofeedback training control orientation moved towards a more internal locus of control. Also, depression scores were significantly reduced six months

after training. Results show that in patients with refractory epilepsy depression is highly correlated with locus of control, in a way that external control orientation relates to high depression scores. Biofeedback is able to improve internal control orientation through personal success mediation.

Upton, A. R., & Longmere, D. (1975). The effects of feedback on focal epileptic discharges in man: A preliminary report. ***Canadian Journal of Neurological Sciences,*** **2, 153-167.** The history of the control of epileptic disturbances by conditioning techniques is reviewed. The preliminary results of a three year trial of feedback techniques in 13 epileptic patients are presented. Thirteen epileptic patients (age 2.5 leads to 39 mean, 15.1 years) with lateralized focal discharges in the EEG were given repeated trials of feedback, the focal discharges being used to trigger auditory and somatosensory stimuli. Dosages and serum levels of medication were unchanged throughout the experimental period. The number of epileptic spikes per 15 seconds was assessed by automatic trend analysis during 20 to 30 minute control, biofeedback and post-feedback epochs. On-going EEG activity was quantified by 8 channel frequency analysis over 10 second epochs. The patients made efforts to increase and decrease the number of spike discharges with and without feedback and the results of both triggered and random auditory, somatosensory, photic and combined stimulation were compared at various intervals over a period of up to three years. A marked reduction in the number of focal discharges was noted in eight (61.5%) patients during and immediately following the sessions. Intermittent biofeedback sessions were not associated with a serial reduction in the number of focal EEG discharges. There was a reduction in the number of clinical epileptic disturbances in six patients (46%) and possible reasons for this improvement are discussed. One patient suffered an increase in focal temporal lobe discharges during triggered and random auditory stimulation whereas there was a marked reduction in the number of discharges during minimal electrical stimulation of the contralateral arm. The need for careful assessment of each patient to determine appropriate feedback stimulation is stressed. One aim of this research has been to assess the feasibility of using miniature units for continuous feedback of focal discharges in epileptic patients.

Walker, J. E. (2008). Power spectral frequency and coherence abnormalities in patients with intractable epilepsy and their usefulness in long-term remediation of seizures using neurofeedback. ***Clinical EEG & Neuroscience*****, 39(4), 203-204.** Medically intractable seizures appear to be highly correlated with focal slow activity (delta or theta). They also correlate highly with decreases in the coherence of theta.

Normalization of focal slowing and of decreased theta coherence will probably be the neurofeedback approaches most likely to decrease or eliminate seizures in future cases. Neurofeedback has been used for over 35 years to reduce the incidence and severity of seizures. With power training to decrease theta and increase the sensorimotor rhythm (12-15 Hz), an average of 82% of patients experienced a significant reduction in seizure frequency, and occasional remissions were seen. Recent improvements using QEEG to guide neurofeedback training have made it possible to eliminate seizures in most patients, even those with intractable seizures. Following our previous study in 2005, we report an additional 25 patients so treated. We also report an analysis of the frequency of QEEG abnormalities in this patient group. All of the intractable epileptic patients had one or more slow foci (excessive theta or delta compared with the normal database). One third had a relative deficiency of beta power. One fourth had a deficiency of absolute delta. Eighteen percent had excessive absolute alpha power, 18% had deficient absolute alpha power, 18% percent had excessive absolute beta power, and 18% percent had deficient absolute beta power. Hypocoherence of theta was found in 75%, and decreases in alpha coherence were noted in 42%. Hypocoherence of beta was found in 50%, and hypocoherence of delta was found in 25%. Increases in alpha coherence were noted in 33%. Seventeen percent had no coherence abnormalities. When most of the power and coherence abnormalities were normalized with neurofeedback training, all the patients became seizure-free; 76% no longer required an anticonvulsant for seizure control.

Walker, J. E., & Kozlowski, G. P. (2005). Neurofeedback treatment of epilepsy. *Child & Adolescent Psychiatric Clinics of North America*, 14(1), 163-176. With electroencephalographic (EEG) biofeedback (or neurofeedback), it is possible to train the brain to de-emphasize rhythms that lead to generation and propagation of seizure and emphasize rhythms that make seizures less likely to occur. With recent improvements in quantitative EEG measurement and improved neurofeedback protocols, it has become possible in clinical practice to eliminate seizures or reduce the amount of medication required to control them. In this article, the history of neurofeedback for epilepsy is presented followed by discussions of the relevant neurophysiology of epilepsy. A model of how neurofeedback might raise the seizure threshold is then presented. Clinical experience using a quantitative EEG-guided approach is described, including a representative case study.

Whitsett, S. F., Lubar, J. F., Holder, G. S., et al. (1982). A double-blind investigation of the relationship between seizure activity and the sleep EEG following EEG

biofeedback training. ***Biofeedback & Self-Regulation,*** **7, 193-209.** The sleep EEGs of eight medically refractory epileptic patients were examined as part of a double-blind, ABA crossover study designed to determine the effectiveness of EEG biofeedback for the control of seizures. The patients were initially reinforced for one of three EEG criteria recorded from electrodes placed over sensorimotor cortex: (a) suppression of 3- to 7-Hz activity, (b) enhancement of 12- to 15-Hz activity, or (c) simultaneous suppression of 3- to 7-Hz and enhancement of 11- to 19-Hz activity. Reinforcement contingencies were reversed during the second or B phase, and then reinstated in their original form during the final A' phase. All-night polysomnographic recordings were obtained at the end of each conditioning phase and were subjected to both visual and computer-based power spectral analyses. Four of the patients showed changes in their nocturnal paroxysmal activity that were either partially or totally consistent with the ABA' contingencies of the study. The spectral data proved difficult to interpret, though two trends emerged from the analyses. Decreases in nocturnal 4- to 7-Hz activity were correlated with decreases in seizure activity, and increases in 8- to 11-Hz activity were correlated with decreases in seizure activity. These findings were shown to strengthen the hypothesis that EEG biofeedback may produce changes in the sleep EEG that are related to seizure incidence.

Wyler, A. R., Robbins, C. A., & Dodrill, C. B. (1979). EEG operant conditioning for control of epilepsy. ***Epilepsia*****, 20, 279-286.** We report the results of 23 severely epileptic patients who were given EEG feedback training. The paradigm reinforced the patients' 18 Hz activity over the scalp approximation of their focus while suppressing temporalis EMG and low frequency EEG activity. In contrast to other studies using EEG feedback, only 43% of patients showed significant changes in seizure occurrence and a lesser number were felt to have benefited clinically. None of our neuropsychological test parameters were helpful in identifying (prospectively or retrospectively) patients most likely to respond to this treatment. Although a few patients were significantly helped by this training, the mechanism for this effect is unclear.

Zhao, L., Liang, Z., Hu, G., & Wu, W. (2005). Nonlinear analysis in treatment of intractable epilepsy with EEG biofeedback. ***Conference Proceedings IEEE Engineering, Medical, & Biological Science*****, 5, 4568-4571.** About 25% epilepsy patients are suffering from medically intractable epileptic seizure. Many studies have shown that electroencephalogram (EEG) biofeedback therapy has the exciting potential for seizure control. In this paper, five patients with intractable epilepsy were trained to increase the production of sensorimotor (12~15Hz) activity and decrease the production of slow theta

(4~7Hz) activity. Nonlinear analyses are proposed to evaluate the effect of biofeedback training. In all the five patients, the complexity and approximate entropy of EEG increased significantly ($P<0.05$) after (about 1-month) the biofeedback treatment.

SLEEP DISORDERS

Arns, M., Kenemans, JL. (2012). Neurofeedback in ADHD and insomnia: Vigilance stabilization through sleep spindles and circadian networks. Neuroscience Biobehavioral Review. In this review article an overview of the history and current status of neurofeedback for the treatment of ADHD and insomnia is provided. Recent insights suggest a central role of circadian phase delay, resulting in sleep onset insomnia (SOI) in a sub-group of ADHD patients. Chronobiological treatments, such as melatonin and early morning bright light, affect the suprachiasmatic nucleus. This nucleus has been shown to project to the noradrenergic locus coeruleus (LC) thereby explaining the vigilance stabilizing effects of such treatments in ADHD. It is hypothesized that both Sensori-Motor Rhythm (SMR) and Slow-Cortical Potential (SCP) neurofeedback impact on the sleep spindle circuitry resulting in increased sleep spindle density, normalization of SOI and thereby affect the noradrenergic LC, resulting in vigilance stabilization. After SOI is normalized, improvements on ADHD symptoms will occur with a delayed onset of effect. Therefore, clinical trials investigating new treatments in ADHD should include assessments at follow-up as their primary endpoint rather than assessments at outtake. Furthermore, an implication requiring further study is that neurofeedback could be stopped when SOI is normalized, which might result in fewer sessions.

Bell, J. S. (1979). The use of EEG theta biofeedback in the treatment of a patient with sleep-onset insomnia. *Biofeedback & Self Regulation*, 4(3), 229-236. In this report, the treatment of a 42-year-old female with a complaint of chronic sleep-onset insomnia is described. Following the unsuccessful use of relaxation training, treatment consisted of 11 sessions of EEG theta rhythm (4--7 Hz) biofeedback. Theta density and five sleepindices were monitored throughout baseline, placebo, and treatment sessions. A significant increase in theta density was accompanied by reports of a decrease in sleep latency and an increase in total sleep time. This improvement was maintained after withdrawal of medication and at 3-month follow-up.

Berner, I., Schabus, M., Wienerroither, T., & Klimesch, W. (2006). The significance of sigma neurofeedback training on sleep spindles and aspects of declarative memory. *Applied Psychophysiology & Biofeedback,* 31(2), 97-114. The functional significance of sleep spindles for overnight memory consolidation and general learning aptitude as well as the effect of four 10-minute sessions of spindle frequency (11.6-16

Hz, sigma) neurofeedback-training on subsequent sleep spindle activity and overnight performance change was investigated. Before sleep, subjects were trained on a paired-associate word list task after having received either neurofeedback training (NFT) or pseudofeedback training (PFT). Although NFT had no significant impact on subsequent spindle activity and behavioral outcomes, there was a trend for enhanced sigma band-power during NREM (stage 2 to 4) sleep after NFT as compared to PFT. Furthermore, a significant positive correlation between spindle activity during slow wave sleep (in the first night half) and overall memory performance was revealed. The results support the view that the considerable inter-individual variance in sleep spindle activity can at least be partly explained by differences in the ability to acquire new declarative information. We conclude that the short NFT before sleep was not sufficient to efficiently enhance phasic spindle activity and/or to influence memory processing. NFT was, however, successful in increasing sigma power, presumably because sigma NFT effects become more easily evident in actually trained frequency bands than in associated phasic spindle activity.

Coursey RD, Frankel BL, Gaarder KR, Mott DE. (1980). A comparison of relaxation techniques with electrosleep therapy for chronic, sleep-onset insomnia a sleep-EEG study. Biofeedback and Self-Regulation. Mar;5(1):57-73.

Two methods of relaxation therapy, electromyograph biofeedback and autogenic training, were compared to a nonrelaxation treatment, electrosleep therapy, in reducing sleep latency among 22 chronic, sleep-onset insomniacs. While none of the electrosleep patients improved on all-night laboratory electroencephalographic sleep records or daily home sleep logs, approximately one-half of the relaxation-treated patients showed marked improvement, which was sustained over a 1-month follow-up period. Although some sleep and treatment variables differentiated relaxation therapy responders from nonresponders, external stress appeared to be the most salient factor. Successful and unsuccessful patients could not be differentiated on any of the psychological variables studied.

Hammer, BU., Colbert, AP., Brown, KA., Llioi, EC. (2011). Neurofeedback for insomnia: a pilot study of Z-score SMR and individualized protocols. Applied Psychophysiology and Biofeedback, 36(4): 251-264. Insomnia is an epidemic in the US. Neurofeedback (NFB) is a little used, psychophysiological treatment with demonstrated usefulness for treating insomnia. Our objective was to assess whether two distinct Z-Score NFB protocols, a modified sensorimotor (SMR) protocol and a sequential, quantitative EEG (sQEEG)-guided, individually designed (IND) protocol, would alleviate sleep and associated daytime dysfunctions of participants with insomnia. Both protocols used instantaneous Z scores to determine reward condition administered when awake. Twelve adults with insomnia, free of other mental and uncontrolled physical illnesses, were randomly assigned to the SMR or IND group. Eight completed this randomized, parallel group, single-blind study. Both groups received fifteen 20-min sessions of Z-Score NFB. Pre-post assessments included sQEEG, mental health, quality of life, and insomnia status. ANOVA yielded significant post-treatment improvement for the combined group on all primary insomnia scores: Insomnia Severity Index (ISI $p<.005$), Pittsburgh Sleep Quality Inventory (PSQI $p<.0001$), PSQI Sleep Efficiency ($p<.007$), and Quality of Life Inventory ($p<.02$). Binomial tests of baseline EEGs indicated a significant proportion of excessively high levels of Delta and Beta power ($p<.001$) which were lowered post-treatment (paired z-tests $p<.001$). Baseline EEGs showed excessive sleepiness and hyperarousal, which improved post-treatment. Both Z-Score NFB groups improved in sleep and daytime functioning. Post-treatment, all participants were normal sleepers. Because there were no significant differences in the findings between the two groups, our future large scale studies will utilize the less burdensome to administer Z-Score SMR protocol.

Hoedlmoser, K., Pecherstorfer, T., Gruber, E., Anderer, P., Doppelmayr, M., Klimesch, W., & Schabus, M. (2008). Instrumental conditioning of human sensorimotor rhythm (12-15 Hz) and its impact on sleep as well as declarative learning. *Sleep*, 31(10), 1401-1408. Study Objectives: To test whether instrumental conditioning f sensorimotor rhythm (SMR; 12-15 Hz) has an impact on sleep parameters as well as declarative memory performance in humans. DESIGN: Randomized, parallel group design. SETTING: 10 instrumental conditioning sessions, pre- and post-treatment investigation including sleep evaluations. PARTICIPANTS: 27 healthy subjects (13 male) Interventions: SMR-conditioning (experimental group) or randomized-frequency conditioning (control group); declarative memory task before and after a 90-min nap. MEASUREMENT AND RESULTS: The experimental group was trained to enhance the amplitude of their SMR-frequency range, whereas the control group participated in a randomized-frequency conditioning program (i.e., every session a different 3-Hz

frequency bin between 7 and 20 Hz). During pre- and post-treatment the subjects had to attend the sleep laboratory to take a 90-min nap (2:00-3:30 pm) and to perform a declarative memory task before and after sleep. The experimental design was successful in conditioning an increase in relative 12-15 Hz amplitude within 10 sessions (d = 0.7). Increased SMR activity was also expressed during subsequent sleep by eliciting positive changes in different sleep parameters (sleep spindle number [d = 0.6], sleep onset latency [d = 0.7]); additionally, this increased 12-15 Hz amplitude was associated with enhancement in retrieval score computed at immediate cued recall (d = 0.9). CONCLUSION: Relative SMR amplitude increased over 10 instrumental conditioning sessions (in the experimental group only) and this "shaping of one's own brain activity" improved subsequent declarative learning and facilitated the expression of 12-15 Hz spindle oscillations during sleep. Most interestingly, these electrophysiological changes were accompanied by a shortened sleep onset latency.

Kinreich, S., Podipsky, I., Jamshy, S., Intrator, N. & Hendler, T. (2014). Neural dynamics necessary and sufficient for transition into pre-sleep induced by EEG neurofeedback. NeuroImage: Aug15(97). 19-28. The transition from being fully awake to pre-sleep occurs daily just before falling asleep; thus its disturbance might be detrimental. Yet, the neuronal correlates of the transition remain unclear, mainly due to the difficulty in capturing its inherent dynamics. We used an EEG theta/alpha neurofeedback to rapidly induce the transition into pre-sleep and simultaneous fMRI to reveal state-dependent neural activity. The relaxed mental state was verified by the corresponding enhancement in the parasympathetic response. Neurofeedback sessions were categorized as successful or unsuccessful, based on the known EEG signature of theta power increases over alpha, temporally marked as a distinct "crossover" point. The fMRI activation was considered before and after this point. During successful transition into pre-sleep the period before the crossover was signified by alpha modulation that corresponded to decreased fMRI activity mainly in sensory gating related regions (e.g. medial thalamus). In parallel, although not sufficient for the transition, theta modulation corresponded with increased activity in limbic and autonomic control regions (e.g. hippocampus, cerebellum vermis, respectively). The post-crossover period was designated by alpha modulation further corresponding to reduced fMRI activity within the anterior salience network (e.g. anterior cingulate cortex, anterior insula), and in contrast theta modulation corresponded to the increased variance in the posterior salience network (e.g. posterior insula, posterior cingulate cortex). Our findings portray multi-level neural dynamics underlying the mental transition from awake to pre-sleep. To initiate the transition, decreased activity was required in external monitoring regions, and to sustain the transition, opposition between the anterior and posterior parts of the salience

network was needed, reflecting shifting from extra- to intrapersonal based processing, respectively.

Ninias, M., Kober, SE., Witte, M., Koschutnig, K. & Neuper, C. (2015) Brain volumetry and self-regulation of brain activity relevant for neurofeedback. Biological Psychology. http://dx.doi.org/10.1016/j.biopsycho.2015.07.009. Neurofeedback is a technique to learn to control brain signals by means of real time feedback. In the present study, the individual ability to learn two EEG neurofeedback protocols - sensorimotor rhythm and gamma rhythm - was related to structural properties of the brain. The volumes in the anterior insula bilaterally, left thalamus, right frontal operculum, right putamen, right middle frontal gyrus, and right lingual gyrus predicted the outcomes of sensorimotor rhythm training. Gray matter volumes in the supplementary motor area and left middle frontal gyrus predicted the outcomes of gamma rhythm training. These findings combined with further evidence from the literature are compatible with the existence of a more general self-control network, which through self-referential and self-control processes regulates neurofeedback learning

Reiner, M., Rozengurt, R. & Barnea, A. (2014). Better than sleep: Theta neurofeedback training accelerates memory consolidation. Biological Psychology:Jan;95(45). 45-53. Consistent empirical results showed that both night and day sleep enhanced memory consolidation. In this study we explore processes of consolidation of memory during awake hours. Since theta oscillations have been shown to play a central role in exchange of information, we hypothesized that elevated theta during awake hours will enhance memory consolidation. We used a neurofeedback protocol, to enhance the relative power of theta or beta oscillations. Participants trained on a tapping task, were divided into three groups: neurofeedback theta; neurofeedback beta; control. We found a significant improvement in performance in the theta group, relative to the beta and control groups, immediately after neurofeedback. Performance was further improved after night sleep in all groups, with a significant advantage favoring the theta group. Theta power during training was correlated with the level of improvement, indicating a clear relationship between memory consolidation, and theta neurofeedback.

Sollfrank, T., Ramsay, A., Perdikis, S., Williamson, J., Murray-Smith, R., Leeb, R., Millan, JdR. & Kubler, A. (2015). The effects of multimodal and enriched feedback on SMR-BCI performance. Clinical Neurophysiology: 127(1). 490-498. Objective: This study investigated the effect of multimodal (visual and auditory) continuous feedback with information about the uncertainty of the input signal on motor imagery based BCI performance. A liquid floating through a visualization of a funnel (funnel feedback) provided enriched visual or enriched multimodal feedback. Methods: In a between subject design 30 healthy SMR-BCI naive participants were provided with either conventional bar feedback (CB), or visual funnel feedback (UF), or multimodal (visual and auditory) funnel feedback (MF). Subjects were required to imagine left and right hand movement and were trained to control the SMR based BCI for five sessions on separate days. Results: Feedback accuracy varied largely between participants. The MF feedback lead to a significantly better performance in session 1 as compared to the CB feedback and could significantly enhance motivation and minimize frustration in BCI use across the five training sessions. Conclusion: The present study demonstrates that the BCI funnel feedback allows participants to modulate sensorimotor EEG rhythms. Participants were able to control the BCI with the funnel feedback with better performance during the initial session and less frustration compared to the CB feedback. Significance: The multimodal funnel feedback provides an alternative to the conventional cursorbar feedback for training subjects to modulate their sensorimotor rhythms.

Schabus, M., Heib DP., Lechinger J., Griessenberger H., Klimesch W., Pawlizki A., Kunz AB., Sterman BM. & Hoedlmoser K. (2014). Enhancing sleep quality and memory in insomnia using instrumental sensorimotor rhythm conditioning. Biological Psychology Jan;95. 126-134. EEG recordings over the sensorimotor cortex show a prominent oscillatory pattern in a frequency range between 12 and 15 Hz (sensorimotor rhythm, SMR) under quiet but alert wakefulness. This frequency range is also abundant during sleep, and overlaps with the sleep spindle frequency band. In the present pilot study we tested whether instrumental conditioning of SMR during wakefulness can enhance sleep and cognitive performance in insomnia. Twenty-four subjects with clinical symptoms of primary insomnia were tested in a counterbalanced within-subjects-design. Each patient participated in a SMR- as well as a sham-conditioning training block. Polysomnographic sleep recordings were scheduled before and after the training blocks. Results indicate a significant increase of 12-15 Hz activity over the course of ten SMR training sessions. Concomitantly, the number of awakenings decreased and slow-wave sleep as well as subjective sleep quality increased. Interestingly, SMR-training enhancement was also found to be associated with overnight memory consolidation and sleep spindle changes indicating a beneficial cognitive effect of the SMR training

protocol for SMR "responders" (16 out of 24 participants). Although results are promising it has to be concluded that current results are of a preliminary nature and await further proof before SMR-training can be promoted as a non-pharmacological approach for improving sleep quality and memory performance.

Sterman, MB., Shouse, MN. (1980). Quantitative analysis of training, sleep EEG and clinical response to EEG operant conditioning in epileptics. Electroencephalography and Clinical Neurophysiology, 49(5-6): 558-579. This report is a follow-up to a previous paper which described seizure rate changes with central cortical EEG feedback training in 8 poorly controlled epileptic subjects. Data examined here include associated training compliance and performance, sleep EEG spectra, clinical EEG and anticonvulsant blood levels. The study employed a double-cross-over, single blind ABA design applied to two subgroups of epileptic patients. Both groups had in common two training periods (A1, A2) in which either 12–15 c/sec (subgroup I, n = 4) or 18--23 c/sec (subgroup II, n = 4) was reinforced in the absence of 6–9 c/sec, movement or epileptiform discharge, and one training period (B) in which 6--9 c/sec was reinforced in the absence of 12--15 or 18--23 c/sec as well as movement and epileptiform discharge. Training periods occurred primarily in the home and lasted 3 months. Compliance with training instructions and response acquisition were demonstrated. Overall anticonvulsant blood levels were low and unrelated to EEG or seizure changes. Clinical EEG findings corresponded to sleep EEG and seizure rate outcomes. Power spectral analysis of sampled non-REM sleep from all-night EEG recordings obtained after each training phase indicated contingency specific changes which were limited to sensorimotor recordings in subgroup I and corresponded to the pattern of seizure rate changes in this group. EEG changes were also limited to sensorimotor cortex in subgroup II, but were linear and paralleled a progressive decrease in seizure rate. Both groups, however, showed the same pattern of EEG changes with seizure reductions; low and high frequencies were reduced and intermediate, rhythmic frequencies increased. Correlational analysis confirmed this relationship. The pattern, duration and topographic specificity of these changes suggested a normalization of sensorimotor EEG substrates related to the EEG feedback training.

Sterman MB. (1977). Sensorimotor EEG operant conditioning: experimental and clinical effects. ***The Pavlovian Journal of Biological Science*****. Apr-Jun;12(2):63-92.** (Abstract to follow.)

SUBSTANCE ABUSE AND ADDICTION DISORDERS

Arani, FD., Rostami, R., Nostratabadi, M. (2012). Effectiveness of neurofeedback training as a treatment for opioid-dependent patients. ***Clinical EEG and Neuroscience*****:41(3). 170-177**. Neurofeedback (NF) training has been employed as a therapeutic method in substance-dependence disorder over the last three decades. The purpose of the present study was to examine the effectiveness of this method on improvement of comorbid neuro-psychological syndromes in opioid-dependence disorder. Psychopathological and craving dimensions and brain activity signals of 20 opioid dependent patients were measured using Symptom Checklist-90-Revised (SCL-90-R), Heroin Craving Questionnaire (HCQ), and Quantitative Electroencephalography (QEEG). All the patients were undergoing pharmacotherapy. They were assigned to two groups that were matched based on SCL-90-R scores, education and age. The experimental group received 30 sessions of NF training in addition to their medicine. The control group received only the usual pharmacotherapy. The probable changes were monitored by reappraisal of all the patients after the treatment. We hypothesized that patients in the experimental group would show more reduction in their comorbid syndromes. The Multivariate Analysis of Covariance (MANCOVA) showed that the experimental group, in comparison with control group, showed significantly more improvement in all three outcome measures. In the SCL-90-R, improvement was noted with the hypochondriacs, obsession, interpersonal sensitivity, aggression, psychosis, and general symptomatic indexes. In the HCQ, improvement was found in the anticipation of positive outcome, desire to use substance, and total average score. Finally, the QEEG showed positive changes in frontal, central and parietal delta, frontal and central theta, parietal alpha and frontal and central Sensory Motor Rhythm (SMR) amplitudes. This study suggests that NF can be used as a therapeutic method to ameliorate abnormalities related to opioid-dependence disorders. The results emphasize the importance of neuropsychological interventions in treatment of substance-dependence disorders.

Burkett, V. S., Cummins, J. M., Dickson, R. M., & Skolnick, M. (2005). An open clinical trial utilizing real-time EEG operant conditioning as an adjunctive therapy in the treatment of crack cocaine dependence. ***Journal of Neurotherapy*****, 9(2), 27-48.** Electroencephalographic (EEG) biofeedback has been employed in substance use disorder (SUD) over the last three decades. The SUD is a complex series of disorders with frequent comorbidities and EEG abnormalities of several types. EEG biofeedback has been employed in conjunction with other therapies and may be useful in enhancing certain outcomes of therapy. Based on published clinical studies and employing efficacy criteria adapted by the Association for Applied Psychophysiology and Biofeedback and the International Society for Neurofeedback and Research, alpha theta training–either alone for alcoholism or in combination with beta training for stimulant and mixed substance abuse and combined with residential treatment programs, is probably efficacious. Considerations of further research design taking these factors into account are discussed and descriptions of contemporary research are given.

Callaway, T.G., Bodenhamer-Davis, E. (2008). Long-term follow-up of a clinical replication of the Peniston Protocol for chemical dependency. *Journal of Neurotherapy* 12(4), 243 - 259. *Introduction*. This study is a long-term follow-up of an early replication of the Peniston EEG biofeedback (EEG-BFB) Protocol for chemical dependency (Peniston & Kulkosky, 1989, 1990). *Method*. This clinical trial included 16 chemically dependent adult participants treated with the Peniston Protocol in a university outpatient clinic between 1993 and 1995. Ten participants were probationers classified as high risk for rearrest. Treatment effects were assessed using pre/posttreatment measures (Beck Depression Inventory, Minnesota Multiphasic Personality Inventory-2) and long-term follow-up of abstinence and rearrest rates. Probationer rearrest rates were compared to an equivalent probation sample (n = 24) that did not receive EEG-BFB. *Results*. Initial Beck Depression Inventory scores indicated mild/moderate depression but were significantly reduced posttreatment to within normal limits. Substantial differences were noted posttreatment on 7 Minnesota Multiphasic Personality Inventory-2 clinical scales suggesting less psychopathology following treatment. Long-term (74-98 months) follow-up indicated that 81.3% (n = 13) participants were abstinent. Rearrest rates and probation revocations for the probationer subgroup were lower than the comparison group (40% vs. 79.16%). *Conclusion*. This study provides evidence of the durability of Peniston Protocol results over time but has the usual limitations of a clinical trial with a small sample, nonrandomized, and uncontrolled design. Implications for further research are discussed including the relevance of recent modifications to the Peniston Protocol and qEEG-based protocols in treating substance abuse.

rCannon, R., Lubar, J., Sokhadze, E., & Baldwin, D. (2008). LORETA Neurofeedback for addiction and the possible neurophysiology of psychological processes influenced: A Case Study and region of interest (ROI) analysis of LNFB in right anterior cingulate cortex (ACC). *Journal of Neurotherapy*,12(4), 227-242. Introduction. This case study explores the efficacy of low-resolution electromagnetic tomographic (LORETA) neurofeedback (LNFB) in the right anterior cingulate cortex (ACC) as a method for addiction treatment and examines the frequency specific effects of this training in eight other regions of the cortex identified as playing an important role in substance use disorders. Methods. This case study was completed with one right-handed, 28-year-old female participant with 3 years of continuous abstinence from polysubstance abuse; her drugs of choice were heroin and alcohol, and she reported an 8-year history of alcohol abuse and a 4-year history of heroin use (IV). She completed 25 sessions of LNFB training in which she increased 14-18 Hz activity in the right ACC. We utilized electrophysiological measures to assess the increase or decrease in eight regions of interest (ROI): the right hippocampus, the right amygdaloid complex, the right orbitofrontal cortex (OFC), the right occipital lobe, the right insular cortex, the right uncus, and two regions in the left prefrontal cortex and compared them using complex linear mixed model and partial correlation procedures. Results. The data indicate significant associations between these limbic and cortical regions. The linear increase in the right ACC was in the desired direction; however, this will require more than 25 sessions to reach significance. The effects of training in the right ACC show significant increase and decrease for all frequencies in specific regions of interest. Conclusion. This is the first study of its kind to explore the relationship between these nine ROI as influenced by LNFB in the right ACC. The data suggest that these regions may play an intricate role in behaviors and characteristics involved in addiction; specific changes in the alpha frequency in limbic regions and increases in associations between regions in the theta frequency may influence personality and other

behaviors associated with addictive traits. This case study illustrates the possible neural mechanisms involved in the negative self-reference associated with addiction even after a significant period of abstinence and possibly offers insight into antecedents to the onset of substance use disorders.

Casanova, M., Baryth, J., El-Baz, A., Tasman, A., Sears, L., & Sokhadze, E. (2012). Repetitive transcranial magnetic stimulation (rTMS) modulates event-related potential (ERP) indices of attention in autism. *Translational Neuroscience*, 3(2) 170-180. In our previous study on individuals with autism spectrum disorder (ASD) (Sokhadze et al., Appl Psychophysiol Biofeedback 34:37-51, 2009a) we reported abnormalities in the attention-orienting frontal event-related potentials (ERP) and the sustained-attention centro-parietal ERPs in a visual oddball experiment. These results suggest that individuals with autism over-process information needed for the successful differentiation of target and novel stimuli. In the present study we examine the effects of low-frequency, repetitive Transcranial Magnetic Stimulation (rTMS) on novelty processing as well as behavior and social functioning in 13 individuals with ASD. Our hypothesis was that low-frequency rTMS application to dorsolateral prefrontal cortex (DLFPC) would result in an alteration of the cortical excitatory/inhibitory balance through the activation of inhibitory GABAergic double bouquet interneurons. We expected to find post-TMS differences in amplitude and latency of early and late ERP components. The results of our current study validate the use of low-frequency rTMS as a modulatory tool that altered the disrupted ratio of cortical excitation to inhibition in autism. After rTMS the parieto-occipital P50 amplitude decreased to novel distracters but not to targets; also the amplitude and latency to targets increased for the frontal P50 while decreasing to non-target stimuli. Low-frequency rTMS minimized early cortical responses to irrelevant stimuli and increased responses to relevant stimuli. Improved selectivity in early cortical responses lead to better stimulus differentiation at later-stage responses as was made evident by our P3b and P3a component findings. These results indicate a significant change in early, middle-latency and late ERP components at the frontal, centro-parietal, and parieto-occipital regions of interest in response to target and distracter stimuli as a result of rTMS treatment. Overall, our preliminary results show that rTMS may prove to be an important research tool or treatment modality in addressing the stimulus hypersensitivity characteristic of autism spectrum disorders.

Clemans, Z., El-Baz, A., Hollifield, M., & Sokhadze, E. (2012). Single trial time-frequency analysis of error processing in PTSD. *Neuroscience Letters*. E-publication. http://dx.doi.org/10.1016/j.neulet.2012.07.051. Error processing studies in psychology and psychiatry are relatively common. Event-related potentials (ERPs) are often used as measures of error processing, two such response-locked ERPs being the error-related negativity (ERN) and the error-related positivity (Pe). The ERN and Pe occur following committed error in reaction time tasks as low frequency (4-8 Hz) electroencephalographic (EEG) oscillations registered at the midline fronto-central sites. We created an alternative method for analyzing error processing using time-frequency analysis in the form of a wavelet transform. A study was conducted in which subjects with PTSD and healthy control completed a forced-choice task. Single trial EEG data from errors in the task were processed using a continuous wavelet transform. Coefficients from the transform that corresponded to the theta range were averaged to isolate a theta waveform in the time-frequency domain. Measures called the time-frequency ERN and Pe were obtained from these waveforms for five different channels and then averaged to obtain a single time-frequency ERN and Pe for each error trial. A comparison of the amplitude and latency for the time-frequency ERN and Pe between the PTSD and control group was performed. A significant group effect was

found on the amplitude of both measures. These results indicate that the developed single trial time-frequency error analysis method is suitable for examining error processing in PTSD and possibly other psychiatric disorders.

deBeus, R. J. (2007). Quantitative electroencephalography-guided versus Scott/Peniston neurofeedback with substance abuse outpatients: A pilot study. *Applied Psychophysiology and Biofeedback*, 35(4), 146-151. Electroencephalographic (EEG) biofeedback has been employed in substance use disorder (SUD) over the last three decades. The SUD is a complex series of disorders with frequent comorbidities and EEG abnormalities of several types. EEG biofeedback has been employed in conjunction with other therapies and may be useful in enhancing certain outcomes of therapy. Based on published clinical studies and employing efficacy criteria adapted by the Association for Applied Psychophysiology and Biofeedback and the International Society for Neurofeedback and Research, alpha theta training–either alone for alcoholism or in combination with beta training for stimulant and mixed substance abuse and combined with residential treatment programs, is probably efficacious. Considerations of further research design taking these factors into account are discussed and descriptions of contemporary research are given.

Dehghani-Arani F, Rostami R & Nadali H. (2013). Neurofeedback training for opiate addiction: improvement of mental health and craving. Appl Psychophysiol Biofeedback. 2013 Jun;38(2):133-41. doi: 10.1007/s10484-013-9218-5. Psychological improvements in patients with substance use disorders have been reported after neurofeedback treatment. However, neurofeedback has not been commonly accepted as a treatment for substance dependence. This study was carried out to examine the effectiveness of this therapeutic method for opiate dependence disorder. The specific aim was to investigate whether treatment leads to any changes in mental health and substance craving. In this experimental study with a pre-post test design, 20 opiate dependent patients undergoing Methadone or Buprenorphine maintenance treatment were examined and matched and randomized into two groups. While both experimental and control groups received their usual maintenance treatment, the experimental group received 30 sessions of neurofeedback treatment in addition. The neurofeedback treatment consisted of sensory motor rhythm training on Cz, followed by an alpha-theta protocol on Pz. Data from the general health questionnaire and a heroin craving questionnaire were collected before and after treatment. Multivariate analysis of covariance showed that the experimental group achieved improvement in somatic symptoms, depression, and total score in general mental health; and in anticipation of positive outcome, desire to use opioid, and relief from withdrawal of craving in comparison with the control group. The study supports the effectiveness of neurofeedback training as a therapeutic method in opiate dependence disorder, in supplement to pharmacotherapy.

Fahrion, S. L., Walters, E. D., Coyne, L., & Allen, T. (1992). Alterations in EEG amplitude, personality factors and brain electrical mapping after alpha theta brainwave training: A controlled case study of an alcoholic in recovery. *Alcoholism: Clinical & Experimental Research*, 16, 547-552. A controlled case study was conducted of effects of EEG alpha and theta brainwave training with a recovering alcoholic patient who experienced craving and fear of relapse after 18 months of abstinence. Training consisted of six sessions of thermal biofeedback to increase central nervous system (CNS) relaxation. Effects were documented with pretreatment and post-treatment personality testing, 20-channel digitized EEG evaluations both under relaxed conditions and under stress, minute-by-minute physiologic recordings of autonomic and EEG data during each

training session, blood pressure, and heart rate indications taken both during relaxation and under stress, and by clinical observation. Results replicated those of a previous controlled study with chronic alcoholic patients not abstinent prior to treatment. New findings include post-treatment indications of more relaxed CNS functioning under stress, and of reduced autonomic activation both during relaxation and under stress. Brain-mapping indications of anxiety associated with painful cold-pressor stimulation were seen only in the pretest readings; at post-test the brain map indicated pain-associated EEG activity in the contralateral somatosensory area, but no apparent anxiety-associated EEG activity. At 4 months post-treatment the patient's wife and colleagues report the patient appears to function in a more relaxed way under the impact of stress, and he reports no longer experiencing craving for alcohol. Overall, support is provided for the possibility that alpha and theta brainwave training may be a useful intervention for the abstinent alcoholic experiencing stress-related craving and fear of relapse.

Goldberg, R. J., et al. (1976). Alpha conditioning as an adjunct treatment for drug dependence: Part I. *International Journal of Addiction*, 11, 1085-1089. The effects of alpha conditioning on the habits of four methadone-maintained patients were assessed. All four learned some control over alpha activity in the 5-week, 10-session training period. The most striking results, however, related to the subjects' substitution of self-initiated mental states associated with alpha for previously used drug-seeking or self-medicating methods of coping with everyday problem situations. All four subjects reported a decrease in illicit drug usage and an increased feeling of self-control. Verification of improvement in adjustment and drug abuse was shown by counseling reports and narcotic screens from the maintenance program.

Gross, E., El-Baz, A. S., Sokhadze, G. E., Sears, L., Casanova, M. F., & Sokhadze, E. M. (2012). Induced EEG gamma oscillation alignment
improves differentiation between autism and ADHD group responses in facial categorization task. *Journal of Neurotherapy*, 16, 78-91.

Children diagnosed with an autism spectrum disorder (ASD) often lack the ability to recognize and properly respond to emotional stimuli. Emotional deficits also characterize children with attention deficit/hyperactivity disorder (ADHD), in addition to exhibiting limited attention span. These abnormalities may effect a difference in the induced EEG gamma wave burst (35-45 Hz) peaked approximately 300-400 ms following an emotional stimulus. Because induced gamma oscillations are not fixed at a definite point in time poststimulus, analysis of averaged EEG data with traditional methods may result in an attenuated gamma burst power. We used a data alignment technique to improve the averaged data, making it a better representation of the individual induced EEG gamma oscillations. A study was designed to test the response of a subject to emotional stimuli, presented in the form of emotional facial expression images. In a four-part experiment, the subjects were instructed to identify gender in the first two blocks of the test, followed by differentiating between basic emotions in the final two blocks (i.e., anger vs. disgust). EEG data were collected from ASD (n = 10), ADHD (n = 9), and control (n = 11) subjects via a 128-channel EGI system, and processed through a continuous wavelet transform and bandpass filter to isolate the gamma frequencies. A custom MATLAB code was used to align the data from individual trials between 200 and 600 ms poststimulus, EEG site, and condition by maximizing the Pearson product-moment correlation coefficient between trials. The gamma power for the 400-

ms window of maximum induced gamma burst was then calculated and compared between subject groups. Condition (anger/disgust recognition, gender recognition) × Alignment × Group (ADHD, ASD, Controls) interaction was significant at most of parietal topographies (e.g., P3-P4, P7-P8). These interactions were better manifested in the aligned data set. Our results show that alignment of the induced gamma oscillations improves sensitivity of this measure in differentiation of EEG responses to emotional facial stimuli in ADHD and ASD.

Hanlon CA., Hartwell KJ., Canterberry M., Li X., Owens M., Lematty T., Prisciandaro JJ., Borckardt J., Brady KT. & George MS. (2013). Reduction of cue-induced craving through real time neurofeedback in nicotine users: The role of region of interest selection and multiple visits. Psychiatry Res. 2013 Jul 30;213(1):79-81. doi: 10.1016/j.pscychresns.2013.03.003. This multi-visit, real-time functional magnetic resonance imaging feedback study demonstrates that treatment-seeking smokers can effectively modulate their behavioral and brain responses to smoking cues. They are more effective at decreasing activity in functionally defined regions involved in "craving" (e.g. ventral anterior cingulate cortex [vACC]) rather than increasing activity in regions involved in "resisting" (e.g. dorsal medial prefrontal cortex [dmPFC]).

Horrell, T., El-Baz, A., Baruth, J., Tasman, A., Sokhadze, G., Stewart, C., & *Sokhadze, E.*_(2010). Neurofeedback effects on evoked and induced EEG gamma band reactivity to drug -related cues in cocaine addiction. *Journal of Neurotherapy*, 14(3), 195-216.

Introduction. Preoccupation with drug and drug-related items is a typical characteristic of cocaine addicted individuals. It has been shown in multiple accounts that prolonged drug use has a profound effect on the EEG recordings of drug addicts when compared to controls during cue reactivity tests. Cue reactivity refers to a phenomenon in which individuals with a history of drug abuse exhibit excessive psychophysiological responses to cues associated with their drug of choice. One of the aims of this pilot study was to determine the presence of an attentional bias to preferentially process drug-related cues using evoked and induced gamma reactivity measures in cocaine addicts before and after biobehavioral treatment based on neurofeedback. Another aim was to show that central sensorimotor rhythm (SMR) amplitude increase and frontal theta control is possible in an experimental outpatient drug users group over 12 neurofeedback sessions. Method. Ten current cocaine abusers participated in this pilot research study using neurofeedback combined with Motivational Interviewing sessions. Eight of them completed all planned pre- and postneurofeedback cue reactivity tests with event-related EEG recording and clinical evaluations. Cue reactivity test represented a visual oddball task with images from the International Affective Picture System and drug-related pictures. Evoked and induced gamma responses to target and nontarget drug cues were analyzed using wavelet analysis. Results. Outpatient participants with cocaine addiction completed the biobehavioral intervention and successfully increased SMR while keeping theta practically unchanged in 12 sessions of neurofeedback training. The addition of Motivational Interviewing helped retain patients in the study. Clinical evaluations immediately after completion of the treatment showed decreased self-reports on depression and stress scores, and urine tests collaborated reports of decreased use of cocaine and marijuana. Effects of neurofeedback resulted in a lower EEG gamma reactivity to drug-related images in a postneurofeedback cue reactivity test. In particular, evoked gamma showed decreases in power to nontarget and to a lesser extent target drug-related cues at all topographies (left, right, frontal, parietal, medial, inferior), whereas induced gamma power

decreased globally to both target and nontarget drug cues. Our findings supported our hypothesis that gamma band cue reactivity measures are sufficiently sensitive functional outcomes of neurofeedback treatment. Both evoked and induced gamma measures were found capable to detect changes in responsiveness to both target and nontarget drug cues. Conclusion. Our study emphasizes the utility of cognitive neuroscience methods based on EEG gamma band measures for the assessment of the functional outcomes of neurofeedback-based biobehavioral interventions for cocaine use disorders. This approach may have significant potential for identifying both physiological and clinical markers of treatment progress. The results confirmed our prediction that EEG changes achieved with neurofeedback training will be accompanied by positive EEG outcomes in a cue reactivity and clinical improvements.

Keith, JR., Ragpay, L., Theodore, D., Schwartz, JM & Ross, JL. (2014). An assessment of an automated EEG biofeedback system for attention deficits in a substance use disorders residential treatment setting. Psychology of Addiction Behaviors: Sept 2014 Early e-pub. Attention deficits are prevalent among individuals with substance use disorders and may interfere with recovery. The present study evaluated the effectiveness of an automated electroencephalogram (EEG) biofeedback system in recovering illicit substance users who had attention deficits upon admission to a comprehensive residential treatment facility. All participants (n = 95) received group, family, and individual counseling. Participants were randomly assigned to 1 of 3 groups that either received 15 sessions of automated EEG biofeedback (AEB), 15 sessions of clinician guided EEG biofeedback (CEB), or 15 additional therapy sessions (AT). For the AEB and CEB groups, operant contingencies reinforced EEG frequencies in the 15-18 Hz (β) and 12-15 Hz (sensorimotor rhythm, "SMR") ranges and reduce low frequencies in the 1-12 Hz (Δ, θ, and α) and 22-30 Hz (high β) ranges. The Test of Variables of Attention (TOVA), a "Go-NoGo" task, was the outcome measure. Attention scores did not change on any TOVA measure in the AT group. Reaction time variability, omission errors, commission errors, and d' improved significantly (all p values < .01) in the AEB and CEB groups. AEB and CEB did not differ significantly from each other on any measure. The results demonstrate that automated neurofeedback can effectively improve attention in recovering illicit substance users in the context of a comprehensive residential substance abuse treatment facility.

Kelly, M. J. (1997). Native Americans, neurofeedback, and substance abuse theory: Three year outcome of alpha/theta neurofeedback training in the treatment of problem drinking among Dine' (Navajo) people. *Journal of Neurotherapy,* 2(3), 24-60. This three year follow-up study presents the treatment outcomes of 19 Dine' (Navajo) clients who completed a culturally sensitive, alpha/theta neurofeedback training program. In an attempt to both replicate the earlier positive studies of Peniston (1989) and to determine if neurofeedback skills would significantly decrease both alcohol consumption and other behavioral indicators of substance abuse, these participants received an average of 40 culturally modified neurofeedback training sessions. This training was adjunctive to their normal 33 day residential treatment. According to DSM-IV criteria for substance abuse, 4 (21%) participants now meet criteria for “sustained full remission”, 12 (63%) for “sustained partial remission”, and 3 (16%) still remain “dependent” (American Psychiatric Association, 1994). The majority of participants also showed a significant increase in “level of functioning” as measured by the DSM-IV Axis V GAF. Subjective reports from participants indicated that their original neurofeedback training had been both enjoyable and self-empowering; an experience generally different from their usual treatment routine of talk-

therapy and education. This internal training also appeared to naturally stimulate significant, but subtle, spiritual experiences and to be naturally compatible with traditional Navajo cultural and medicine-ways. At the three-year follow-up interview, participants typically voiced that these experiences, and their corresponding insights, had been helpful both in their ability to cope and in their sobriety. From an outside perspective, experienced nurses also reported unexpected behavioral improvements during the participant's initial training. Additionally, administrators and physicians generally found the objective feedback and verification quality of neurofeedback protocols compatible with their own beliefs. An attempt has also been made to conceptualize the outcome analysis of this study within both a culturally specific and universal socio/bio/ environmental context.

Lamontague, Y., Hand, I., Annable, L., et al. (1975). Physiological and psychological effects of alpha and EMG feedback training with college drug users: A pilot study. ***Canadian Psychiatric Association Journal*****, 20, 337-349.** Twenty-four volunteer college students who were regular drug users were randomly allocated to three training groups of equal size: alpha feedback, EMG feedback and a yoked control group. The subjects were unaware of which feedback condition they received and were asked to practice at home during a six-month follow-up period in order to achieve a relaxed state similar to that experienced during training. No group was successful in retaining gains made in their alpha levels during each session, but the EMG group significantly reduced their muscular activity during training and retained the improvement during follow-up. The alpha and yoked groups did not greatly improve their EMG during training but at follow-up achieved the same levels as the EMG group. There was evidence to suggest that a reduction in drug use among light and medium users was maintained during follow-up. Significant and lasting improvements were made by each group in the duration and quality of their sleep and anxiety levels were reduced.

Passini, F., Watson, C. G., Dehnel, L., Herder, J., & Watkins, B. (1977). Alpha wave biofeedback training therapy in alcoholics. ***Journal of Clinical Psychology*****, 33(1), 292-299.** This investigation evaluated the therapeutic efficacy of alpha-wave biofeedback treatment for alcoholics. Twenty-five Ss were compared to a matched control group before and after administration of a 3-week alpha-wave biofeedback regimen on a wide variety of criteria that included State-Trait Anxiety, the MMPI, Multiple Affect Adjective Check List, Zuckerman's Sensation Seeking Scale, Watson's Anhedonia Scale, the Brief Psychiatric Rating Scale, and baseline alpha. The experimental Ss received 10 hour-long alpha training sessions. The experimentals showed more improvement than did controls on alpha production and two anxiety measure. Contradictory results appeared on two suspicion/paranoia measures. Alpha training appeared useful in the treatment of anxiety, but not other problems. However, the absence of significant correlations between amount of change on alpha and the anxiety measures suggests that the improvement may be due to a placebo effect.

Peniston, E. G., & Kulkosky, P. J. (1989). Alpha-theta brainwave training and beta-endorphin levels in alcoholics. Alcohol: Clinical & Experimental Research, 13(2), 271-279. An alpha-theta brainwave-biofeedback training program was applied as a novel treatment technique for chronic alcoholics. Following a temperature-biofeedback pretraining phase, experimental subjects completed 15 30-min sessions of alpha-theta biofeedback training. Compared to a nonalcoholic control group and a traditionally treated alcoholic control group, alcoholics receiving brainwave training (BWT) showed significant increases in percentages of EEG record in alpha and theta rhythms, and increased alpha rhythm amplitudes. Alcoholics receiving BWT showed a gradual increase

in alpha and theta brain rhythms across the 15 experimental sessions. These experimentally treated alcoholics showed sharp reductions in self-assessed depression (Beck's Depression Inventory) compared to the control groups. Alcoholics receiving standard medical treatment (abstinence, group psychotherapy, antidepressants) showed a significant elevation in serum beta-endorphin levels at the conclusion of the experiment. This neuropeptide is an index of stress and a stimulant of caloric (e.g., ethanol) intake. Application of brainwave treatment, a relaxation therapy, appears to counteract the increase in circulating beta-endorphin levels seen in the control group of alcoholics. 13-month follow-up data indicate sustained prevention of relapse in alcoholics that completed alpha-theta brainwave training.

Saxby, E., & Peniston, E. G. (1995). Alpha-theta brainwave neurofeedback training: An effective treatment for male and female alcoholics with depressive symptoms. Journal of Clinical Psychology, 51(5), 685-693. This was an experimental study of 14 alcoholic outpatients using the Peniston and Kulkosky (1989, 1991) brainwave treatment protocol for alcohol abuse. After temperature biofeedback pretraining, experimental subjects completed 20 40-minute sessions of alpha-theta brainwave neurofeedback training (BWNT). Experimentally treated alcoholics with depressive syndrome showed sharp reductions in self-assessed depression (Beck's Depression Inventory). On the Millon Clinical Multiaxial Inventory-I, the experimental subjects showed significant decreases on the BR scores: schizoid, avoidant, dependent, histrionic, passive-aggression, schizotypal, borderline, anxiety, somatoform, hypomanic, dysthmic, alcohol abuse, drug abuse, psychotic thinking, and psychotic depression. Twenty-one-month follow-up data indicated sustained prevention of relapse in alcoholics who completed BWNT.

Simkin, DR., Thatcher, RW. & Lubar, J. (2014). Quantitative EEGB and Neurofeedback in Children and adolescents: Anxiety disorders, depressive disorders, comorbid addiction and attention-deficit/hyperactivity disorder and brain injury. *Child and Adolescent Psychiatric Clinics of North America*:23(3). 427-464. This article explores the science surrounding neurofeedback. Both surface neurofeedback (using 2-4 electrodes) and newer interventions, such as real-time z-score neurofeedback (electroencephalogram [EEG] biofeedback) and low-resolution electromagnetic tomography neurofeedback, are reviewed. The limited literature on neurofeedback research in children and adolescents is discussed regarding treatment of anxiety, mood, addiction (with comorbid attention-deficit/hyperactivity disorder), and traumatic brain injury. Future potential applications, the use of quantitative EEG for determining which patients will be responsive to medications, the role of randomized controlled studies in neurofeedback research, and sensible clinical guidelines are considered.

Sokhadze, T.M., Cannon, R., & Trudeau, D.L. (2008). EEG biofeedback as a treatment for substance use disorders: Review, rating of efficacy and recommendations for future research, *Applied Psychophysiology & Biofeedback*, 33(1), 1-28. Electroencephalographic (EEG) biofeedback has been employed in substance use disorder (SUD) over the last three decades. The SUD is a complex series of disorders with frequent comorbidities and EEG abnormalities of several types. EEG biofeedback has been employed in conjunction with other therapies and may be useful in enhancing certain outcomes of therapy. Based on published clinical studies and employing efficacy criteria adapted by the Association for Applied Psychophysiology and Biofeedback and the International Society for Neurofeedback and Research, alpha theta training-either alone

for alcoholism or in combination with beta training for stimulant and mixed substance abuse and combined with residential treatment programs, is probably efficacious. Considerations of further research design taking these factors into account are discussed and descriptions of contemporary research are given.

Sokhadze, E., Stewart, C., Hollifield, M., El-Baz, A.., Singh, S., & Tasman, A. (2008). Attentional bias to stress-related pictorial cues in cocaine addiction comorbid with PTSD. ***Journal of Neurotherapy*****,12(4), 205-225.** Cocaine addiction places a specific burden on mental health services through its comorbidity with other psychiatric disorders. Treatment of patients with cocaine abuse is more complicated when addiction is co-occurring with PTSD. This study used dense-array event-related potential (ERP) technique to investigate whether the patients with this form of dual diagnosis display excessive reactivity to both trauma and drug cues as compared to neutral cues. Cue reactivity refers to a phenomenon in which individuals with a history of drug dependence exhibit verbal, physiological, and behavioral responses to cues associated with their preferred substance of abuse. This study explores ERP differences associated with cue-related responses to both drug and trauma cues in a three-category oddball task using neutral, drug-, and trauma-related pictorial stimuli. The study was conducted on 14 cocaine dependent subjects, 11 subjects with cocaine dependence comorbid with PTSD, and 9 age- and gender-matched control subjects. A 128-channel Electrical Geodesics EEG system was used to record ERP during the visual three-category oddball task with three categories (neutral, drug, stress) of affective pictures. Patients with cocaine dependence and PTSD, as compared to patients with only cocaine addiction and control subjects, showed excessive cue reactivity to both drug- and trauma-related visual stimuli. Most profound differences were found in the amplitude and latency of frontal P3a, and centro-parietal P3b ERP components. Group differences were found as well between patients with cocaine abuse (both addiction-only and dual diagnosis groups) vs. controls on most ERP measures for drug-related cues. We propose that the employed ERP cue reactivity variables could be used as valuable functional outcome measures in dually diagnosed drug addicts undergoing behavioral treatment.

Sokhadze, E., Stewart, C. M., Tasman, A., Daniels, R., & Trudeau, D. (2011). Review of rationale for neurofeedback application in adolescent substance abusers with comorbid disruptive behavioral disorders. ***Journal of Neurotherapy*****, 15, 232-261.** Neurofeedback is a type of operant conditioning in which an individual modifies the frequency, amplitude, or other characteristic of his or her own brain activity as measured by EEG. Neurofeedback-training-based neurotherapy is one of the potentially efficacious nonpharmacological treatment options for substance use disorders (SUD) in adults, but it is also a very promising as a treatment modality for adolescents, especially those with stimulant abuse and attention and conduct problems. There is practically no literature on the use of neurofeedback in adolescent drug abusers. Treatment of attention-deficit/hyperactivity disorder (ADHD) with neurofeedback has already gained substantial empirical support in recent years. Short-term effects were shown to be comparable to those of stimulant medication at the behavioral and neuropsychological level, leading to significant decreases of inattention, hyperactivity, and impulsivity. In addition, neurofeedback results in concomitant improvement and normalizations of neurophysiological patterns assessed with EEG, event-related potentials (ERPs), and fMRI. Neurofeedback techniques may be of special interest for adolescent medicine because of the high comorbidity of SUD and ADHD in adolescents. ADHD is often comorbid with other disruptive behavioral disorders such as conduct disorder and oppositional defiant disorder. Techniques that combine classic ADHD neurofeedback approaches

with behavioral addiction treatment hold special interest for adolescents with dual diagnosis. They are medication free and thus both minimize opportunities for prescribed medication misuse and diversions and are free of medication side effects. Furthermore, neurofeedback directly acts on the specific brain activity that are known to be altered in SUD and ADHD. By providing low-risk and medication-free therapy for both ADHD and SUD, neurofeedback is an option for practitioners reluctant to prescribe controlled substances to ADHD adolescents at risk for substance abuse.

Sokhadze, E., Baruth, J., Sears, L., Sokhadze, G. E., El-Baz, A., Williams, E., Klapheke, R., & Casanova, M. F. (2012). Event related potentials study of attention regulation during illusory figure categorization task in ADHD, autism spectrum disorders, and typical children. ***Journal of Neurotherapy*****,16, 12-31.** Autism spectrum disorders (ASD) and attention deficit/hyperactivity disorder (ADHD) are very common developmental disorder that share some similar symptoms of social, emotional, and attentional deficits. This study is aimed to help understand the differences and similarities of these deficits using analysis of dense-array event-related potentials (ERP) during an illusory figure recognition task. Although ADHD and ASD seem very distinct, they have been shown to share some similarities in their symptoms. Our hypothesis was that children with ASD will show less pronounced differences in ERP responses to target and nontarget stimuli as compared to typical children and, to a lesser extent, ADHD. Participants were children with ASD (N=16), ADHD (N=16), and controls (N=16). EEG was collected using a 128-channel EEG system. The task involved the recognition of a specific illusory shape, in this case a square or triangle, created by three or four inducer disks. There were no between-group differences in reaction time (RT) to target stimuli, but both ASD and ADHD committed more errors; specifically, the ASD group had statistically higher commission error rate than controls. Posterror RT in ASD group was exhibited in a posterror speeding rather than corrective RT slowing typical for the controls. The ASD group also demonstrated an attenuated error-related negativity as compared to ADHD and controls. The fronto-central P200, N200, and P300 were enhanced and less differentiated in response to target and nontarget figures in the ASD group. The same ERP components were marked by more prolonged latencies in the ADHD group as compared to both ASD and typical controls. The findings are interpreted according to the “minicolumnar” hypothesis proposing existence of neuropathological differences in ASD and ADHD, specifically minicolumnar number/width morphometry spectrum differences. In autism, a model of local hyperconnectivity and long-range hypoconnectivity explains many of the behavioral and cognitive deficits present in the condition, whereas the inverse arrangement of local hypoconnectivity and long-range hyperconnectivity in ADHD explains some deficits typical for this disorder. The current ERP study supports the proposed suggestion that some between-group differences could be manifested in the frontal ERP indices of executive functions during performance on an illusory figure categorization task.

Trudeau, D. L. (2005). Applicability of brain wave biofeedback to substance use disorder in adolescents. Child & Adolescent Psychiatric Clinics of North America, 14(1), 125-136. Neurofeedback treatment for addictions in adults is probably efficacious, and several reported approaches are described with their indications. Neurofeedback is promising as a treatment modality for adolescents, especially those with stimulant abuse and attention and conduct problems. It is attractive as a medication-free, neurophysiologic, and self-actualizing treatment for a substance-based, brain-impaired and self-defeating disorder. More research, beginning with case reporting, is needed to assess use and efficacy in adolescents.

Watson, C. G., Herder, J., & Passini, F. T. (1978). Alpha biofeedback therapy in alcoholics: An 18-month follow-up. Journal of Clinical Psychology, 34(3), 765-769. In an earlier study on patients with alcohol problems, an experimental group given 10 hour-long alpha biofeedback training sessions showed greater improvement on State and Trait Anxiety scores than did a control sample. In the present study an 18-month follow-up was done on those Ss. The differences between the experimentals and controls in State and Trait Anxiety after 18 months were essentially identical to the differences between them immediately after treatment, which indicates that alpha training had long-range therapeutic effects. A difference between the groups on the Alcohol Rehabilitation Follow up Questionnaire also suggested that alpha training may have been associated with some reduction in alcohol consumption as well.

OTHER

(CURRENTLY: TINNITUS | MOTOR LEARNING | TOURETTE'S SYNDROME | FMRI AND EEG TRAINING STRUCTURAL BRAIN CHANGES | CANCER | PAIN | COGNITIVE DECLINE | STROKE SYSTEMATIC REVIEW OF NFB AND BFB | GENERAL APPICATIONS)

(Papers in alphabetical order)

CANCER: Alvarez J, Meyer FL, Granoff DL & Lundy A. (2013). The Effect of EEG Biofeedback on Reducing Postcancer Cognitive Impairment. Integr Cancer Ther. 2013 Apr 12. [Epub ahead of print]. BACKGROUND AND HYPOTHESES. Postcancer cognitive impairment (PCCI) is observed in a substantial number of breast cancer survivors, persisting for as long as 20 years in some subgroups. Although compensatory strategies are frequently suggested, no restorative interventions have yet been identified. This study examined the feasibility of EEG biofeedback ("neurofeedback") and its potential effectiveness in reducing PCCI as well as the fatigue, sleep disturbance, and psychological symptoms that frequently accompany PCCI. STUDY DESIGN: This was a 6-month prospective study with a waitlist control period followed by an active intervention. Participants were female breast cancer survivors (n = 23), 6 to 60 months postchemotherapy, with self-reported cognitive impairment. METHODS: Four self-report outcome measures (Functional Assessment of Cancer Therapy-Cognitive Function [FACT-Cog], Functional Assessment of Chronic Illness Therapy-Fatigue [FACIT-Fatigue], Pittsburgh Sleep Quality Index [PSQI], and Brief Symptom Inventory [BSI]-18) were administered 3 times during a 10-week waitlist control period, 3 times during a 10-week (20-session) neurofeedback training regimen, and once at 4 weeks post neurofeedback. RESULTS: All 23 participants completed the study, demonstrating the feasibility of EEG biofeedback in this population. Initially, the sample demonstrated significant dysfunction on all measures compared with general population norms. Repeated-measures ANOVAs revealed strongly significant improvements ($P < .001$) on all 4 cognitive measures (perceived cognitive impairment, comments from others, perceived cognitive abilities, and impact on quality of life [QOL]), the fatigue scale, and the 4 psychological scales (somatization, depression, anxiety and global severity index) as well as on 3 of 8 sleep scales (quality, daytime dysfunction, and global). Two of the other sleep scales (latency and disturbance) were significant at $P < .01$, and 1 (use of medication) at $P < .05$; 2 were not significant. Improvements were generally linear across the course of training, and were maintained at the follow-up testing. At the follow-up testing, the sample no longer differed significantly from normative populations on 3 of the 4 FACT-Cog measures (impairment, impact on QOL, and comments), FACIT-Fatigue, PSQI sleep quality and habitual efficiency, or any of the BSI-18 measures of psychological disturbance. CONCLUSIONS: Data from this limited study suggest that EEG biofeedback has potential for reducing the negative cognitive and emotional sequelae of cancer treatment as well as improving fatigue and sleep patterns.

TINNITUS: Dohrmann K., Weisz N., Schlee W., Hartmann T. & Elbert T. (2007). Neurofeedback for treating tinnitus. Prog Brain Res. 2007;166:473-85. Many individuals with tinnitus have abnormal oscillatory brain activity. Led by this finding, we have developed a way to normalize such pathological activity by neurofeedback techniques (Weisz et al. (2005). PLoS Med., 2: e153). This is achieved mainly through enhancement of tau activity, i.e., oscillatory activity produced in perisylvian regions within the alpha frequency range (8-12 Hz) and concomitant reduction in delta power range (0.5-4 Hz). This activity is recorded from electrodes placed on the frontal scalp. We have found that modification of the tau-to-delta ratio significantly reduces tinnitus intensity. Participants who successfully modified their oscillatory pattern profited from the treatment to the extent that the tinnitus sensation became completely abolished. Overall, this neurofeedback training was significantly superior in reducing tinnitus-related distress than frequency discrimination training.

STROKE: Finnigan S, van Putten MJ. (2013). EEG in ischaemic stroke: quantitative EEG can uniquely inform (sub-)acute prognoses and clinical management. *Clin Neurophysiol*. Jan;124(1):10-9. doi: 10.1016/j.clinph.2012.07.003. Epub 2012 Aug 2. Investigations of (sub-)acute ischaemic stroke (IS) employing quantitative electroencephalographic (QEEG) methods, in concert with other assessments, are reviewed. Numerous outcomes from hundreds of patients collectively indicate that (sub-)acute QEEG indices from standard systems can uniquely inform clinical management, particularly prognostication of outcomes from IS. Two classes of QEEG indices have proven particularly informative. The first quantifies the power of abnormal, slow activity relative to that of faster activity and the second, interhemispheric voltage asymmetry (broadband). Both have been identified as statistically significant predictors of outcomes assessed (via routine clinical scales) in the weeks and months following IS. Furthermore both have demonstrated higher predictive value than concomitant neurological assessments and scales, and to improve upon outcome prediction afforded by neuroimaging alone. These indices also may continuously provide unique, real-time insights into the efficacy of thrombolytic therapy, prior to clinical changes. Two key applications of QEEG which should prove valuable for future clinical management of IS are: (1) continuous, acute monitoring to inform about the efficacy of thrombolysis and decisions about potential additional interventions, and; (2) brief, subacute recording to inform outcome prognostication and clinical decisions about, for example, rehabilitation strategies. Ongoing research and technological developments will continue to facilitate clinical translation of QEEG investigations reviewed herein.

COGNITIVE DECLINE: Fonseca LC, Tedrus GM, Carvas PN, Machado EC. (2103). Comparison of quantitative EEG between patients with Alzheimer's disease and those with Parkinson's disease dementia. Clin Neurophysiol. 2013 Jun 5. pii: S1388-2457(13)00636-6. doi: 10.1016/j.clinph.2013.05.001. [Epub ahead of print]. OBJECTIVE: Dementia frequently occurs in Parkinson's disease (PD) but its pathophysiological basis is little known. Comparative EEG studies of Alzheimer's disease (AD) and Parkinson's disease dementia (PDD) are still rare, but could provide knowledge on the different pathophysiological mechanisms involved. The objective of the present study was to comparatively evaluate the absolute power and coherence on the EEG for patients with AD and PDD. METHODS: This study assessed 38 adults with AD, 12 with PDD, 31 with Parkinson's disease without dementia, and 37 controls (CG) by a neurological evaluation, CERAD

neuropsychological battery, executive functions tests and qEEG, calculating global absolute powers for the delta, theta, alpha and beta bands and inter- and intra-hemispheric coherences. RESULTS: The delta and theta powers were highest in PDD and lowest in CG ($p<0.05$). The beta frontal-occipital inter-hemispheric coherence was highest in PDD ($p<0.05$). Whereas, alpha and beta frontal inter-hemispheric coherence was highest in PDD and lowest in AD ($p<0.05$). CONCLUSION: These results suggest that qEEG power and coherence measures are different in AD and PDD. SIGNIFICANCE: These qEEG differences must be related to the distinct mechanisms of cortical neural connections in AD and PDD.

FMRI AND EEG TRAINING AND STRUCTURAL BRAIN CHANGES: Ghaziri J, Tucholka A, Larue V, Blanchette-Sylvestre M, Reyburn G, Gilbert G, Lévesque J, Beauregard M. Neurofeedback Training Induces Changes in White and Gray Matter. Clin EEG Neurosci. 2013 Mar 26. The main objective of this structural magnetic resonance imaging (MRI) study was to investigate, using diffusion tensor imaging, whether a neurofeedback training (NFT) protocol designed to improve sustained attention might induce structural changes in white matter (WM) pathways, purportedly implicated in this cognitive ability. Another goal was to examine whether gray matter (GM) volume (GMV) might be altered following NFT in frontal and parietal cortical areas connected by these WM fiber pathways. Healthy university students were randomly assigned to an experimental group (EXP), a sham group, or a control group. Participants in the EXP group were trained to enhance the amplitude of their $\beta 1$ waves at F4 and P4. Measures of attentional performance and MRI data were acquired one week before (Time 1) and one week after (Time 2) NFT. Higher scores on visual and auditory sustained attention were noted in the EXP group at Time 2 (relative to Time 1). As for structural MRI data, increased fractional anisotropy was measured in WM pathways implicated in sustained attention, and GMV increases were detected in cerebral structures involved in this type of attention. After 50 years of research in the field of neurofeedback, our study constitutes the first empirical demonstration that NFT can lead to microstructural changes in white and gray matter.

TINNITUS: Hartmann T, Lorenz I., Müller N., Langguth B. & Weisz N. (2013). The Effects of Neurofeedback on Oscillatory Processes Related to Tinnitus. Brain Topogr. Although widely used, no proof exists for the feasibility of neurofeedback for reinstating the disordered excitatory-inhibitory balance, marked by a decrease in auditory alpha power, in tinnitus patients. The current study scrutinizes the ability of neurofeedback to focally increase alpha power in auditory areas in comparison to the more common rTMS. Resting-state MEG was measured before and after neurofeedback (n = 8) and rTMS (n = 9) intervention respectively. Source level power and functional connectivity were analyzed with a focus on the alpha band. Only neurofeedback produced a significant decrease in tinnitus symptoms and-more important for the context of the study-a spatially circumscribed increase in alpha power in right auditory regions. Connectivity analysis revealed higher outgoing connectivity in a region ultimately neighboring the area in which power increases were observed. Neurofeedback decreases tinnitus symptoms and increases alpha power in a spatially circumscribed manner. In addition, compared to a more established brain stimulation-based intervention, neurofeedback is a promising approach to renormalize the excitatory-inhibitory imbalance putatively underlying tinnitus. This study is the first to demonstrate the feasibility of focally enhancing alpha activity in tinnitus patients by means of neurofeedback.

PAIN: Jensen MP, Gertz KJ, Kupper AE, Braden AL, Howe JD, Hakimian S, Sherlin LH. (2013). Steps toward developing an EEG biofeedback treatment for chronic pain. Appl Psychophysiol Biofeedback. 2013 Jun;38(2):101-8. doi: 10.1007/s10484-013-9214-9. Chronic pain, usually refractory to analgesics, is a significant problem for many individuals with spinal cord injury (SCI). Preliminary studies suggest that electroencephalography (EEG) biofeedback (also known as neurofeedback, NF) has the potential to help patients with otherwise refractory chronic pain. However, there remain many unanswered questions about the effects and mechanisms of this treatment. We studied 13 individuals with SCI and chronic pain with NF. Ten of the 13 individuals completed 4 sessions each of three different neurofeedback protocols assigned in random order for a total of 12 NF sessions. All three protocols had similar immediate effects on pain intensity. In addition, the participants reported modest pre- to post-treatment decreases in worst pain and pain unpleasantness following completion of the 12 NF sessions. These improvements were maintained at 3-month follow-up. The majority of the participants felt they benefited from and were satisfied with the treatment. No significant effects on measures of other outcome domains (sleep quality, pain interference and fatigue) were observed, although there was a non-significant trend for an increase in fatigue. Finally, pre- to post-treatment changes in EEG bandwidth activity, consistent with the training protocols, were observed in θ and α but not β frequencies. The findings provide preliminary support for the potential efficacy of NF for the treatment of SCI-related pain, and suggest that further clinical studies are warranted.

GENERAL: Larsen, S. & Sherlin, L. (2013). Neurofeedback: an emerging technology for treating central nervous system dysregulation. Psychiatr Clin North Am. 2013 Mar;36(1):163-8. doi: 10.1016/j.psc.2013.01.005. Neurofeedback is a machine-mediated noninvasive treatment modality based on the analysis and "feeding back" of electroencephalogram brainwaves, which has shown efficacy with a variety of central nervous system-based problems. It has special application where patients have adverse reaction to psychopharmacologic treatments and psychotherapy, cognitive behavioral therapy, and dialectical behavior therapy have proved ineffective. Treatment modalities include active forms based on operant conditioning, involving a subject's response to stimuli. Neurofeedback is strong in clinical confirmations of efficacy (case studies) and has thus far limited controlled studies in the peer-reviewed journals.

TINNITUS: Moazami-Goudarzi, M., Michels, L., Weitz, N., Jeanmonod, D. (2010). Temporo-insular enhancement of EEG low and high frequencies in patients with chronic tinnitus. QEEG study of chronic tinnitus patients. BMC Neuroscience. 11:40. http://www.biomedcentral.com/1471-2202/11/40. Background: The physiopathological mechanism underlying the tinnitus phenomenon is still the subject of an ongoing debate. Since oscillatory EEG activity is increasingly recognized as a fundamental hallmark of cortical integrative functions, this study investigates deviations from the norm of different resting EEG parameters in patients suffering from chronic tinnitus. Results: Spectral parameters of resting EEG of male tinnitus patients (n = 8, mean age 54 years) were compared to those of age-matched healthy males (n = 15, mean age 58.8 years). On average, the patient group exhibited higher spectral power over the frequency range of 2-100 Hz. Using LORETA source analysis, the generators of delta, theta, alpha and beta power increases were localized dominantly to left auditory (Brodmann Areas (BA) 41,42, 22), temporo-parietal, insular posterior, cingulate

anterior and parahippocampal cortical areas. Conclusions: Tinnitus patients show a deviation from the norm of different resting EEG parameters, characterized by an overproduction of resting state delta, theta and beta brain activities, providing further support for the microphysiological and magnetoencephalographic evidence pointing to a thalamocortical dysrhythmic process at the source of tinnitus. These results also provide further confirmation that reciprocal involvements of both auditory and associative/paralimbic areas are essential in the generation of tinnitus.

MOTOR LEARNING: Ros T., Munneke MA., Parkinson LA. & Gruzelier JH. (2013). Neurofeedback facilitation of implicit motor learning. Biol Psychol. doi: 10.1016/j.biopsycho.2013.04.013. BACKGROUND*:* Mu rhythm desynchronization via EEG-neurofeedback (NFB) has been previously shown to induce durable motor-cortical disinhibition for at least 20min. It was hypothesized that the presentation of a novel procedural learning task immediately after this NFB protocol would boost motor performance. METHOD: The protocol consisted of firstly activating the right primary motor cortex with a single session of Mu (8-12Hz) suppression via NFB for a total of 30min. Shortly after, and with their non-dominant (left) hand, subjects (n=10) performed the serial reaction time task (SRTT), which is used to assess reaction time improvement over multiple trials. During another occasion (1 week before/after), the same subjects were tested on a different sequence without prior NFB, as part of a counterbalanced control condition. RESULTS: Compared to a "cross-over" condition without NFB, subjects who received NFB immediately prior to SRTT performance exhibited a significantly faster rate of learning, reflected in a greater reduction of reaction times across blocks (p=0.02). This occurred in the absence of explicit awareness of a repeating sequence. Moreover, no significant differences were observed between conditions in error rate or reaction time variability. CONCLUSION: Our results suggest that a single NFB session may be directly used to facilitate the early acquisition of a procedural motor task, and are the first to demonstrate that neurofeedback effects could be exploited immediately after individual training sessions so as to boost behavioural performance and learning.

FMRI AND EEG TRAINING AND STRUCTURAL BRAIN CHANGES: Ruiz S, Buyukturkoglu K, Rana M, Birbaumer N, Sitaram R. (2013) Real-time fMRI brain computer interfaces: Self-regulation of single brain regions to networks. Biol Psychol. 2013 May 1. doi: 10.1016/j.biopsycho.2013.04.010. With the advent of brain computer interfaces based on real-time fMRI (rtfMRI-BCI), the possibility of performing neurofeedback based on brain hemodynamics has become a reality. In the early stage of the development of this field, studies have focused on the volitional control of activity in circumscribed brain regions. However, based on the understanding that the brain functions by coordinated activity of spatially distributed regions, there have recently been further developments to incorporate real-time feedback of functional connectivity and spatio-temporal patterns of brain activity. The present article reviews the principles of rtfMRI neurofeedback, its applications, benefits and limitations. A special emphasis is given to the discussion of novel developments that have enabled the use of this methodology to achieve self-regulation of the functional connectivity between different brain areas and of distributed brain networks, anticipating new and exciting applications for cognitive neuroscience and for the potential alleviation of neuropsychiatric disorders.

SYSTEMATIC REVIEW OF NFB AND BFB: Schoenberg, PL. & David, AS. (2014). Biofeedback for psychiatric disorders: A systematic review. Applied Psychophysiology and Biofeedback:39(2). 109-135. Biofeedback potentially provides non-invasive, effective psychophysiological interventions for psychiatric disorders. The encompassing purpose of this review was to establish how biofeedback interventions have been used to treat select psychiatric disorders [anxiety, autistic spectrum disorders, depression, dissociation, eating disorders, schizophrenia and psychoses] to date and provide a useful reference for consultation by clinicians and researchers planning to administer a biofeedback treatment. A systematic search of EMBASE, MEDLINE, PsycINFO, and WOK databases and hand searches in Applied Psychophysiology and Biofeedback, and Journal of Neurotherapy, identified 227 articles; 63 of which are included within this review. Electroencephalographic neurofeedback constituted the most investigated modality (31.7%). Anxiety disorders were the most commonly treated (68.3%). Multi-modal biofeedback appeared most effective in significantly ameliorating symptoms, suggesting that targeting more than one physiological modality for bio-regulation increases therapeutic efficacy. Overall, 80.9% of articles reported some level of clinical amelioration related to biofeedback exposure, 65.0% to a statistically significant ($p < .05$) level of symptom reduction based on reported standardized clinical parameters. Although the heterogeneity of the included studies warrants caution before explicit efficacy statements can be made. Further development of standardized controlled methodological protocols tailored for specific disorders and guidelines to generate comprehensive reports may contribute towards establishing the value of biofeedback interventions within mainstream psychiatry.

TINNITUS: Sedley, W., Gander, PE., Kumar, S., Oya, H. . . . . Griffiths, TD. (2015). Intracranial mapping of a cortical tinnitus system using residual inhibition. Current Biology Report (open access) http://dx.doi.org/10.1016/j.cub.2015.02.075. Tinnitus can occur when damage to the peripheral auditory system leads to spontaneous brain activity that is interpreted as sound. Many abnormalities of brain activity are associated with tinnitus, but it is unclear how these relate to the phantom sound itself, as opposed to predisposing factors or secondary consequences. Demonstrating ''core'' tinnitus correlates (processes that are both necessary and sufficient for tinnitus perception) requires high-precision recordings of neural activity combined with a behavioral paradigm in which the perception of tinnitus is manipulated and accurately reported by the subject. This has been previously impossible in animal and human research. Here we present extensive intracranial recordings from an awake, behaving tinnitus patient during short-term modifications in perceived tinnitus loudness after acoustic stimulation (residual inhibition), permitting robust characterization of core tinnitus processes. As anticipated, we observed tinnitus-linked low-frequency (delta) oscillations, thought to be triggered by low-frequency bursting in the thalamus. Contrary to expectation, these delta changes extended far beyond circumscribed auditory cortical regions to encompass almost all of auditory cortex, plus large parts of temporal, parietal, sensorimotor, and limbic cortex. In discrete auditory, parahippocampal, and inferior parietal ''hub'' regions, these delta oscillations interacted with middle frequency (alpha) and high-frequency (beta and gamma) activity, resulting in a coherent system of tightly coupled oscillations associated with high level functions including memory and perception.

MOTOR LEARNING: Sterman, M. B., Howe, R. D., & Macdonald, L. R. (1970). Facilitation of spindle-burst sleep by conditioning of electroencephalographic activity while awake. *Science*, 167, 1146-1148. A slow-

wave electroencephalographic rhythm recorded from the sensorimotor cortex of the waking cat has been correlated behaviorally with the suppression of movement. Facilitation of this rhythm through conditioning selectively enhances a similar pattern recorded during sleep, the familiar spindle burst. The training also produced longer epochs of undisturbed sleep. The specific neural mechanism manipulated during wakefulness appears to function also in sleep and to be involved with the regulation of phasic motor behavior.

TOURETTE'S SYNDROME: Tansey, MA. (1989). A simple and a complex tic (Tourette's Syndrome): Their response to EEG sensorimotor rhythm biofeedback training. International Journal of Psychophysiology:4. 91-97. This study presents a clinical treatment regime for the treatment of tic manifestation, both simple and complex. The response of a case of simple tic and a case of complex tic (Giles de la Tourette's syndrome) to EEG sensorimotor rhythm biofeedback training are presented. Specifically, the simple and the complex tic, both of long duration, were eliminated via this EEG biofeedback training procedure. It is hypothesized that this exercising of the sensorimotor cortex resulted in increased activation of this cerebrocortical subsystem and was reflected in increased voluntary muscle control and a heightened threshold for random motor discharge, resulting in the elimination of both tics as in the response of cases of epilepsy with motor involvement to EEG sensorimotor rhythm biofeedback training. The additional psychophysiologic sequelae of the complex tic-attention deficit disorder-remediated in the manner of the response of learning-disabled to EEG sensorimotor rhythm biofeedback training.

FMRI AND EEG TRAINING AND STRUCTURAL BRAIN CHANGES: Zotev V., Phillips R., Yuan H., Misaki M. & Bodurka J. (2013) **Self-regulation of human brain activity using simultaneous real-time fMRI and EEG neurofeedback. Neuroimage. doi: 10.1016/j.neuroimage.2013.04.126.** Neurofeedback is a promising approach for non-invasive modulation of human brain activity with applications for treatment of mental disorders and enhancement of brain performance. Neurofeedback techniques are commonly based on either electroencephalography (EEG) or real-time functional magnetic resonance imaging (rtfMRI). Advances in simultaneous EEG-fMRI have made it possible to combine the two approaches. Here we report the first implementation of simultaneous multimodal rtfMRI and EEG neurofeedback (rtfMRI-EEG-nf). It is based on a novel system for real-time integration of simultaneous rtfMRI and EEG data streams. We applied the rtfMRI-EEG-nf to training of emotional self-regulation in healthy subjects performing a positive emotion induction task based on retrieval of happy autobiographical memories. The participants were able to simultaneously regulate their BOLD fMRI activation in the left amygdala and frontal EEG power asymmetry in the high-beta band using the rtfMRI-EEG-nf. Our proof-of-concept results demonstrate the feasibility of simultaneous self-regulation of both hemodynamic (rtfMRI) and electrophysiological (EEG) activities of the human brain. They suggest potential applications of rtfMRI-EEG-nf in the development of novel cognitive neuroscience research paradigms and enhanced cognitive therapeutic approaches for major neuropsychiatric disorders, particularly depression.

QEEG

Arns, M. & Gordon, E. (2014). Quantitative EEG (QEEG) in psychiatry: Diagnostic or prognostic use? Clinical Neurophysiology: 125(8). 1504-1506. In July 2013 the FDA approved marketing of the 'first brain wave test to help assess children and teens for ADHD'1 which is commercialized by NEBA.2 This brain wave test employs the often-published Theta/Beta ratio obtained from the EEG and this milestone has generated significant debate about its veracity, clinical utility and scalability. Most of the media referred to it as a first brain test to diagnose children with ADHD. So should we be positive or cautious about this unprecedented endorsement of EEG into the psychiatric diagnostic
process? Or perhaps a bit of both? On one hand it finally heralds an FDA sanctioned objective biological brain marker into Psychiatry and Pediatrics, which will hopefully be exemplar of more to come. On the other hand it may inadvertently be over-used simplistically as a diagnostic tool.

Brust-Carmona H, Valadez G, Flores-Avalos B, Martínez JA, Sánchez A, Rodríguez MA, Peñaloza Y & Yáñez O. (2103). Absolute power of cortical oscillations and their topographical distribution in a sample of young adults during resting wakefulness and unspecific attention]. [Article in Spanish] Rev Invest Clin. 2013 Jan-Feb;65(1):52-64. INTRODUCTION: The EEG records neuronal membrane potential oscillations that depend on the morpho-functional characteristics of the membrane and of modifications by postsynaptic excitatory (PSEP) and inhibitory (PSIP) potentials. The quantitative EEG (qEEG) measures the absolute power (AP) of oscillations separated in frequencies, resulting from the interaction among subcortical-cortical-subcortical ensembles. The hypothesis is that neuronal networks function at a given frequency and that their APs are codes that, by becoming synchronized in diverse ensembles, generate behavior. OBJECTIVE: To establish the spectral power of cortical oscillations under diverse study paradigms and in different populations. In particular, to identify the AP and topographical distribution of four cerebral frequency bands under resting wakefulness and activation, and to integrate results into a database to establish comparison standards. MATERIAL AND METHODS: Undergraduate students, average age of 20.6 +/- 2.6 years, who participated voluntarily in the study. Recordings were made with a Nicolet EEG. We chose, in the first stage, closed eyes (CE) three samples of 12 s each. In the second stage, we chose pairs of 6 s samples, first with CE and then with OE. For their analysis, we applied the Welch periodogram and we plotted the average AP (AAP) and standard deviation (SD) of delta, theta, alpha, and beta per lead. Differences were compared through non-parametric tests (Wilcoxon and Dunnett T3); setting statistical significance at a = 0.05. RESULTS: Average APs of each frequency band differ significantly in intensity and topographic distribution generating a profile of each rhythm. When opening the eyes, rhythms desynchronized significantly at different intensities in the diverse leads, except for beta in the left fronto-frontal lead. DISCUSSION: Results indicate the existence of cortical ensembles that synchronize at a determined frequency and are modified by visual stimulation, indicating the effects of the subcortico-cortical circuits. The integrated database provides comparison standards to support diagnoses and treatments.

Daly I., Nicolaou N., Nasuto SJ. & Warwick K. (2013) Automated Artifact Removal From the Electroencephalogram: A Comparative Study. Clin EEG Neurosci. PMID: 23666954. Contamination of the electroencephalogram (EEG) by artifacts greatly reduces the quality of the recorded signals. There is a need for automated artifact removal methods. However, such methods are rarely evaluated against one another via rigorous criteria, with results often presented based upon visual inspection alone. This work presents a comparative study of automatic methods for removing blink, electrocardiographic, and electromyographic artifacts from the EEG. Three methods are considered; wavelet, blind source separation (BSS), and multivariate singular spectrum analysis (MSSA)-based correction. These are applied to data sets containing mixtures of artifacts. Metrics are devised to measure the performance of each method. The BSS method is seen to be the best approach for artifacts of high signal to noise ratio (SNR). By contrast, MSSA performs well at low SNRs but at the expense of a large number of false positive corrections.

Haneef Z, Levin HS, Frost JD Jr, Mizrahi EM. (2013). Electroencephalography and quantitative electroencephalography in mild traumatic brain injury. *J Neurotrauma.* 2013 Apr 15;30(8):653-6. doi: 10.1089/neu.2012.2585. Mild traumatic brain injury (mTBI) causes brain injury resulting in electrophysiologic abnormalities visible in electroencephalography (EEG) recordings. Quantitative EEG (qEEG) makes use of quantitative techniques to analyze EEG characteristics such as frequency, amplitude, coherence, power, phase, and symmetry over time independently or in combination. QEEG has been evaluated for its use in making a diagnosis of mTBI and assessing prognosis, including the likelihood of progressing to the post concussive syndrome (PCS) phase. We review the EEG and qEEG changes of mTBI described in the literature. An attempt is made to separate the findings seen during the acute, subacute, and chronic phases after mTBI. Brief mention is also made of the neurobiological correlates of qEEG using neuroimaging techniques or in histopathology. Although the literature indicates the promise of qEEG in making a diagnosis and indicating prognosis of mTBI, further study is needed to corroborate and refine these methods.

Khoury S, Chouchou F, Amzica F, Giguère JF, Denis R, Rouleau GA, Lavigne GJ. (2013). Rapid EEG activity during sleep dominates in mild traumatic brain injury patients with acute pain. *J Neurotrauma*. 2013 Apr 15;30(8):633-41. doi: 10.1089/neu.2012.2519. Epub 2013 Apr 18. Chronic pain is a highly prevalent post-concussion symptom occurring in a majority of patients with mild traumatic brain injury (mTBI). About half of patients with mTBI report sleep-wake disturbances. It is known that pain can alter sleep quality in this population, but the interaction between pain and sleep is not fully understood. This study aimed to identify how pain affects subjective sleep (Pittsburgh Sleep Quality Index [PSQI]), sleep architecture, and quantitative electroencephalographic (qEEG) brain activity after mTBI. Twenty-four mTBI patients complaining of sleep-wake disturbances, with and without pain (8 and 16, respectively), were recruited 45 (±22.7) days post-trauma on average. Data were compared with those of 18 healthy controls (no sleep or pain complaints). The PSQI, sleep architecture, and qEEG activity were analyzed. Pain was assessed using questionnaires and a 100-mm visual analogue scale. Patients with mTBI reported three times poorer sleep quality than controls on the PSQI. Sleep architecture significantly differed between patients with mTBI and controls but was within normal range. Global qEEG showed lower delta (deep sleep) and higher beta and gamma power (arousal) at

certain EEG derivations in patients with mTBI compared with controls ($p<0.04$). Patients with mTBI with pain, however, showed greater increase in rapid EEG frequency bands, mostly during REM sleep, and beta bands in non-REM sleep compared with patients with mTBI without pain and controls ($p<0.001$). Pain in patients with mTBI was associated with more rapid qEEG activity, mostly during REM sleep, suggesting that pain is associated with poor sleep and is a critical factor in managing post-concussion symptoms.

Koberda JL., Moses A., Koberda P. & Koberda L. (2013). Clinical Advantages of Quantitative Electroencephalogram (QEEG)-Electrical Neuroimaging Application in General Neurology Practice. Clin EEG Neurosci. EPub: Mar 26. QEEG-electrical neuroimaging has been underutilized in general neurology practice for uncertain reasons. Recent advances in computer technology have made this electrophysiological testing relatively inexpensive. Therefore, this study was conducted to evaluate the clinical usefulness of QEEG/electrical neuroimaging in neurological practice. Over the period of approximately 6 months, 100 consecutive QEEG recordings were analyzed for potential clinical benefits. The patients who completed QEEG were divided into 5 groups based on their initial clinical presentation. The main groups included patients with seizures, headaches, post-concussion syndrome, cognitive problems, and behavioral dysfunctions. Subsequently, cases were reviewed and a decision was made as to whether QEEG analysis contributed to the diagnosis and/or furthered patient's treatment. Selected and representative cases from each group are presented in more detail, including electrical neuroimaging with additional low-resolution electromagnetic tomography analysis or using computerized cognitive testing. Statistical analysis showed that QEEG analysis contributed to 95% of neurological cases, which indicates great potential for wider application of this modality in general neurology. Many patients also began neurotherapy, depending on the patient's desire to be involved in this treatment modality.

Liechti, MD., Valko, L., Muller, UC., Mirko Dohnert, M., Drechsler, R., Steinhausen, H. & Brandeis, D. (2012). Diagnostic value of resting electroencephalogram in attention-deficit/hyperactivity disorder across the lifespan. Brain Topography: Online Oct 2012. The resting electroencephalogram (EEG) reflects development and arousal, but whether it can support clinical diagnosis of attention-deficit/hyperactivity disorder (ADHD) remains controversial. Here we examined whether theta power and theta/beta ratio are consistently elevated in ADHD and younger age as proposed. Topographic 48-channel EEG from 32 children (8-16 years) and 22 adults (32-55 years) with ADHD and matched healthy controls (n = 30 children/21 adults) was compared. Following advanced artefact correction, resting EEG was tested for increased theta and theta/beta activity due to ADHD and due to normal immaturity. Discriminant analyses tested classification performance by ADHD and age using these EEG markers as well as EEG artefacts and deviant attentional event-related potentials (ERPs). No consistent theta or theta/beta increases were found with ADHD. Even multivariate analyses indicated only marginal EEG power increases in children with ADHD. Instead, consistent developmental theta decreases were observed, indicating that maturational lags of fewer than 3 years would have been detected in children. Discriminant analysis based on proposed simple spectral resting EEG markers was successful for age but not for ADHD (81 vs. 53 % accuracy). Including ERP markers and EEG artefacts improved discrimination, although not to diagnostically useful levels. The lack of consistent spectral resting EEG abnormalities in ADHD despite consistent developmental effects casts doubt upon conventional

neurometric approaches towards EEG-based ADHD diagnosis, but is consistent with evidence that ADHD is a heterogeneous disorder, where the resting state is not consistently characterised by maturational lag.

Wang, Q. & Sourina, O. (2013). Real-time mental arithmetic task recognition from EEG signals. IEEE Trans Neural Syst Rehabil Eng:21(). 225-32. Electroencephalography (EEG)-based monitoring the state of the user's brain functioning and giving her/him the visual/audio/tactile feedback is called neurofeedback technique, and it could allow the user to train the corresponding brain functions. It could provide an alternative way of treatment for some psychological disorders such as attention deficit hyperactivity disorder (ADHD), where concentration function deficit exists, autism spectrum disorder (ASD), or dyscalculia where the difficulty in learning and comprehending the arithmetic exists. In this paper, a novel method for multifractal analysis of EEG signals named generalized Higuchi fractal dimension spectrum (GHFDS) as roposed and applied in mental arithmetic task recognition from EEG signals. Other features such as power spectrum density (PSD), autoregressive model (AR), and statistical features were analyzed as well. The usage of the proposed fractal dimension spectrum of EEG signal in combination with other features improved the mental arithmetic task recognition accuracy in both multi-channel and one-channel subject-dependent algorithms up to 97.87% and 84.15% correspondingly. Based on the channel ranking, four channels were chosen which gave the accuracy up to 97.11%. Reliable real-time neurofeedback system could be implemented based on the algorithms proposed in this paper.

FMRI AND OTHER BRAIN IMAGING

Florin, E. & Baillet, S. (2015). The brain's resting state activity is shaped by synchronized cross-frequency coupling of neural oscillations NeuroImage: 111 26-35. Functional imaging of the resting brain consistently reveals broad motifs of correlated blood oxygen level dependent (BOLD) activity that engages cerebral regions from distinct functional systems. Yet, the neurophysiological processes underlying these organized, large-scale fluctuations remain to be uncovered. Using magnetoencephalography (MEG) imaging during rest in 12 healthy subjects we analyze the resting state networks and their underlying neurophysiology. We first demonstrate non-invasively that cortical occurrences of high-frequency oscillatory activity are conditioned to the phase of slower spontaneous fluctuations in neural ensembles. We further show that resting-state networks emerge from synchronized phase-amplitude coupling across the brain. Overall, these findings suggest a unified principle of local-to-global neural signaling for long-range brain communication.

Paul, RH., Gunstad, J., Cooper, N. & Williams, LM., Clark, CR., Cohen, RA., Lawrence, JJ & Gordon, E. (2007). Cross-cultural assessment of neurophysiological performance and electrical brain function measures: Additional validation of an international brain database. International Journal of Neuroscience:117: 549-568. Previous studies have revealed significant differences in performance on non-language
dependent cognitive tests across international settings among younger individuals, with less pronounced differences evident among older individuals (>54 years of age). The present study examined a broad range of cognitive performance as well as electrophysiological indices of brain function in a multisite and international context. A total of 200 individuals in the United States, 233 individuals in Europe, and 829 individuals in Australia were administered a standardized computerized neuropsychological battery, and complementary electroencephalogram (EEG) recordings were completed. Results revealed no significant differences in cognitive function or electrophysiology across the three continents. Similarly, although there was a main effect for age, the interaction between age and continent was not significant in any of the omnibus analyses. These findings indicate a high degree of similarity in neurocognitive and electrophysiological function among individuals
residing in developed Western cultures, consistent with a trait-like status and the high heritability of the EEG.

Pasqual-Marqui, RD., Lehmann, D., Faber, P., Milz, P., Kochi, K., Yoshimura, M., Nishida, K., Isotani, T. & Kinoshita, T. (2006). The resting microstate (RMN): Cortical distributions, dynamics, and frequency specific information flow. A brain microstate is characterized by a unique, fixed spatial distribution of electrically active neurons with time varying amplitude. It is hypothesized that a microstate implements a functional/physiological state of the brain during which specific neural computations are performed. Based on this hypothesis, brain electrical activity is modeled as a time sequence of non-overlapping microstates with variable, finite durations (Lehmann and Skrandies 1980, 1984; Lehmann et al 1987). In this study, EEG recordings from 109 participants during eyes closed resting condition are modeled with four microstates. In a first part, a new confirmatory statistics method is introduced for the determination of the cortical distributions of electric neuronal activity that generate each microstate. All microstates have common posterior cingulate

generators, while three microstates additionally include activity in the left occipital/parietal, right occipital/parietal, and anterior cingulate cortices. This appears to be a fragmented version of the metabolically (PET/fMRI) computed default mode network (DMN), supporting the notion that these four regions activate sequentially at high time resolution, and that slow metabolic imaging corresponds to a low-pass filtered version. In the second part of this study, the microstate amplitude time series are used as the basis for estimating the strength, directionality, and spectral characteristics (i.e., which oscillations are preferentially transmitted) of the connections that are mediated by the microstate transitions. The results show that the posterior cingulate is an important hub, sending alpha and beta oscillatory information to all other microstate generator regions. Interestingly, beyond alpha, beta oscillations are essential in the maintenance of the brain during resting state.