Neurofeedback and Increased Processing Speed and Cognitive Impact
Relevant Research Abstracts

The first 3 abstracts (1-3) cover effects of neurofeedback on cognitive performance.

The second four (4-7) of the abstracts discuss the effect of Neurofeedback on TOVA in clinical series.
TOVA is a measure of attention, including speed and accuracy.

The remaining abstracts 8-12 discuss the effect of NFB on event related potentials, a neurological measure which can indicate certain types of processing speed.

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Abstract: 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.

RESULTS: 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.


Abstract: 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 meseencephalic-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.

**Enhancing cognitive control through neurofeedback: a role of gamma-band activity in managing episodic retrieval.**

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Abstract : Neural synchronization has been proposed to be the underlying mechanism for exchanging and integrating anatomically distributed information and has been associated with a myriad of cognitive domains, including visual feature binding, top-down control, and long-term memory. Moreover, it seems that separate frequency bands have different functions in these cognitive processes. Here we studied whether neurofeedback training designed either to increase local gamma band activity (GBA+; 36-44 Hz), or local beta band activity (BBA+; 12-20 Hz), would have an impact on performance of behavioral tasks measuring short-term and long-term episodic binding. Our results show that GBA-enhancing neurofeedback training increased occipital GBA within sessions, and occipital and frontal GBA across sessions. Both groups showed an increase of GBA coherence between frontal and occipital areas, but the BBA+ group increased BBA coherence between these areas as well.

**RESULTS:** Neurofeedback training had profound effects on behavior. First, we replicated earlier findings that enhancing GBA led to greater flexibility in handling (selectively retrieving) episodic bindings, which points to a role of GBA in top-down control of memory retrieval. Moreover, the long-term memory task revealed a double dissociation: GBA-targeted training improved recollection, whereas BBA-targeted training improved familiarity memory. We conclude that GBA is important for controlling and organizing memory traces of relational information in both short-term binding and long-term memory, while frontal-occipital coherence in the beta band may facilitate familiarity processes.

**Post WISC-R and TOVA improvement with QEEG guided neurofeedback training in mentally retarded: a clinical case series of behavioral problems.**

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According to the DSM-IV, Mental Retardation is significantly sub-average general intellectual functioning accompanied by significant limitations in adaptive functioning in at least two of the following skill areas: communication, self-care, home living, social/interpersonal skills, use of community resources, self-direction, functional academic skills, work, leisure, health and safety. In pilot work, we have seen positive clinical effects of Neurofeedback (NF) applied to children with Trisomy 21 (Down Syndrome) and other forms of mental retardation. Given that many clinicians use NF in Attention Deficit Hyperactivity Disorder and Generalized Learning Disability cases, we studied the outcomes of a clinical case series using Quantitative EEG (QEEG) guided NF in the treatment of mental retardation. All 23 subjects received NF training. The QEEG data for most subjects had increased theta, alpha, and coherence abnormalities. A few showed increased delta over the cortex. Some of the subjects were very poor in reading and some had illegible handwriting, and most subjects had academic failures, impulsive behavior, and very poor attention, concentration, memory problems, and social skills. This case series shows the impact of QEEG-guided NF training on these clients' clinical outcomes. Fourteen out of 23 subjects formerly took medications without any improvement. Twenty-three subjects ranging from 7-16 years old attending private learning centers were
previously diagnosed with mental retardation (severity of degree: from moderate to mild) at various university hospitals. Evaluation measures included QEEG analysis, WISC-R (Wechsler Intelligence Scale for Children-Revised) IQ test, TOVA (Test of Variables of Attention) test, and DPC-P (Developmental Behaviour Checklist) were filled out by the parents. NF trainings were performed by Lexicor Biolex software. NX-Link was the commercial software reference database used to target the treatment protocols, along with the clinical judgment of the first author. QEEG signals were sampled at 128 samples per second per channel and electrodes were placed according to the International 10-20 system. Between 80 and 160 NF training sessions were completed, depending on the case. None of the subjects received any special education during NF treatment. Two subjects with the etiology of epilepsy were taking medication, and the other 21 subjects were medication-free at the baseline. Twenty-two out of 23 patients who received NF training showed clinical improvement according to the DPC-P with QEEG reports. Nineteen out of 23 patients showed significant improvement on the WISC-R, and the TOVA. For the WISC-R test, 2 showed decline on total IQ due to the decline on some of the subtests, 2 showed no improvement on total IQ although improvement was seen on some of the subtests, however even these cases showed improvement on QEEG and DPC-P. This study provides the first evidence for positive effects of NF treatment in mental retardation. The results of this study encourage further research. http://www.ncbi.nlm.nih.gov/pubmed/20307014

The effectiveness of neurofeedback and stimulant drugs in treating AD/HD: part II. Replication.
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This study replicated T. R. Rossiter and T. J. La Vaque (1995) with a larger sample, expanded age range, and improved statistical analysis. Thirty-one ADIHD patients who chose stimulant drug (MED) treatment were matched with 31 patients who chose a neurofeedback (EEG) treatment program. EEG patients received either office (n = 14) or home (n = 17) neurofeedback. Stimulants for MED patients were titrated using the Test of Variables of Attention (TOVA). EEG (effect size [ES] = 1.01-1.71) and MED (ES = 0.80-1.80) groups showed statistically and clinically significant improvement on TOVA measures of attention, impulse control, processing speed, and variability in attention. The EEG group demonstrated statistically and clinically significant improvement on behavioral measures (Behavior Assessment System for Children, ES = 1.16-1.78, and Brown Attention Deficit Disorder Scales, ES = 1.59). TOVA gain scores for the EEG and MED groups were not significantly different. More importantly, confidence interval and nonequivalence null hypothesis testing confirmed that the neurofeedback program produced patient outcomes equivalent to those obtained with stimulant drugs. An effectiveness research design places some limitations on the conclusions that can be drawn. http://www.ncbi.nlm.nih.gov/pubmed/15707253

EEG and behavioral changes following neurofeedback treatment in learning disabled children.
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Neurofeedback (NFB) is an operant conditioning procedure, by which the subject learns to control his/her EEG activity. On one hand, Learning Disabled (LD) children have higher values of theta EEG absolute a and relative power than normal children, and on the other hand, it has been shown that minimum alpha absolute power is necessary for adequate performance. Ten LD children were selected with higher than normal ratios of theta to alpha absolute power (theta/alpha). The Test Of Variables of Attention (TOVA) was applied. Children were divided into two groups in order to maintain similar IQ values, TOVA values, socioeconomical status, and gender for each group. In the experimental group, NFB was applied in the region with highest ratio, triggering a sound each time the ratio fell below a threshold value. Noncontingent reinforcement was given to the other group. Twenty half-hour sessions were applied, at a rate of 2 per week. At the end of the 20 sessions, TOVA, WISC and EEG were obtained. There was significant improvement in WISC performance in the experimental group that was not observed in the control group.

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EEG absolute power decreased in delta, theta, alpha and beta bands in the experimental group. Control children only showed a decrease in relative power in the delta band. All changes observed in the experimental group and not observed in the control group indicate better cognitive performance and the presence of greater EEG maturation in the experimental group, which suggests that changes were due not only to development but also to NFB treatment.


**Neurofeedback combined with training in metacognitive strategies: effectiveness in students with ADD.**

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A review of records was carried out to examine the results obtained when people with Attention Deficit Disorder (ADD) received 40 sessions of training that combined neurofeedback with the teaching of metacognitive strategies. While not a controlled scientific study, the results, including pre- and post-measures, are consistent with previously published research concerning the use of neurofeedback with children. A significant addition is that a description of procedures is included. The 111 subjects, 98 children (age 5 to 17) and 13 adults (ages 18 to 63), attended forty 50-min sessions, usually twice a week. Feedback was contingent on decreasing slow wave activity and increasing fast wave activity for most subjects. Metacognitive strategies related to academic tasks were taught when the feedback indicated the client was focused. Some clients also received temperature and/or EDR biofeedback during some sessions.

Initially, 30 percent of the children were taking stimulant medications (Ritalin), whereas 6 percent were on stimulant medications after 40 sessions. Pre- and post-testing results were available for one or more of the following: the Test of Variables of Attention (TOVA, n = 76), Wechsler Intelligence Scales (WISC-R, WISC-III, or WAIS-R, n = 68), Wide Range Achievement Test (WRAT 3, n = 99), and the electroencephalogram assessment (QEEG) providing a ratio of theta (4-8 Hz) to beta (16-20 Hz) activity (n = 66).

**RESULTS:** Significant improvements (p < .001) were found in ADD symptoms (inattention, impulsivity, and variability of response times on the TOVA), in both the ACID pattern and the full-scale scores of the Wechsler Intelligence Scales, and in academic performance on the WRAT 3. The average gain for the full scale IQ equivalent scores was 12 points. A decrease in the EEG ratio of theta/beta was also observed. These data are important because they provide an extension of results from earlier studies (Lubar, Swartwood, Swartwood, & O'Donnell, 1995; Linden, Habib, & Radojevic, 1996). They also demonstrate that systematic data collection in a private educational setting produces helpful information that can be used to monitor students' progress and improve programs. Because this clinical work is not a controlled scientific study, the efficacious treatment components cannot be determined. Nevertheless, the positive outcomes of decreased ADD symptoms plus improved academic and intellectual functioning suggest that the use of neurofeedback plus training in metacognitive strategies is a useful combined intervention for students with ADD. Further controlled research is warranted.


**Changes in cognitive evoked potentials during non pharmacological treatment in children with attention deficit/hyperactivity disorder.**

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Attention deficit/hyperactivity disorder (ADHD) is one of the most widely spread condition of school aged children affecting 5% of children of this age. The unified consensus of the precise diagnosis of this condition is still absent. This fact encourages the researchers to seek the alternative neurometric tools which will help the clinicians in diagnosis making process of ADHD. The neurophysiologic approaches especially event-related potentials (ERPs) are mostly important from this point of view. The later response of ERPs (P3) reflects the most important parts of executive functioning frequently affected in ADHD children - the process of mental effortfullness to select the

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appropriate behavior and decision making. Besides the diagnosis the treatment of ADHD is also the point of concern of neurologists and neurophysiologists. In recent years EEG biofeedback (Neurofeedback-NF) have become the alternative treatment as in some cases pharmacological drugs are non effective. The positive impact of NF was based on improvement detected by various questionnaires which are less valid but its effectiveness on ERPs parameters is still unknown. Thus we aimed to study the changes of ERPs after NF therapy.

METHODS: We have studied 93 children with ADHD of combined subtype (ADHDcom) without any kind of pharmacological treatment. Age range 9-12 years. The children were divided into two subgroups: The first ADHDcom-1 (48 children) were children where NF treatment was carried out and the second subgroup of ADHDcom-2 (45 children) were non treated children.

RESULTS: We have observed statistically significant improvement of parameters of later response like P3 in ADHD-1 compared with ADHD-2 whereas NF was non effective for earlier component like N1. CONCLUSIONS: NF can positively affect on the P3 parameters which is very important in ADHD children as P3 reflects the speed of information processing as well as selection of appropriate action and decision making which are frequently affected in ADHD children.  


[Neurofeedback training in children with ADHD: behavioral and neurophysiological effects].


In a multicentre randomised controlled trial, we evaluated the clinical efficacy of neurofeedback (NF) training in children with ADHD and investigated the mechanisms underlying a successful training. We used an attention skills training, coupled with the training setting and demands made upon participants, as the control condition. At the behavioural level, NF was superior to the control group concerning core ADHD symptomatology as well as associated domains. For the primary outcome measure (improvement in the FBB-HKS total score), the effect size was .60. The same pattern of results was obtained at the 6-month follow-up. Thus, NF may be seen as a clinically effective module in the treatment of children with ADHD. At the neurophysiological level (EEG, ERPs), specific effects for the two NF protocols, theta/beta training, and training of slow cortical potentials were demonstrated. For example, for theta/beta training, a decrease of theta activity in the EEG was associated with a reduction of ADHD symptomatology. SCP training was accompanied inter alia by an increase in the contingent negative variation in the attention network test; thus, children were able to allocate more resources for preparation. EEG- and ERP-based predictors were also found. The present article reviewed the findings of the original papers related to the trial and outlines future research topics.  


Neurofeedback in children with ADHD: specific event-related potential findings of a randomized controlled trial.


OBJECTIVE: In a randomized controlled trial, we could demonstrate clinical efficacy of neurofeedback (NF) training for children with ADHD (Gevensleben et al., 2009a). The present investigation aimed at learning more about the neuronal mechanisms of NF training. METHODS: Children with ADHD either completed a NF training or a computerized attention skills training (ratio 3:2). NF training consisted of one block of theta/beta training and one block of slow cortical potential (SCP) training, each comprising 18 training units. At three times (pre-training, between the two training blocks and at post-training), event-related potentials (ERP) were recorded during the Attention Network Test. ERP analysis focused on the P3, reflecting inter alia attentional resources for stimulus evaluation, and the contingent negative variation (CNV), primarily related to cognitive preparation.

RESULTS: After NF training, an increase of the CNV in cue trials could be observed, which was specific for the SCP training. A larger pre-training CNV was associated with a larger reduction of ADHD symptomatology for SCP
CONCLUSIONS: CNV effects reflect neuronal circuits underlying resource allocation during cognitive preparation. These distinct ERP effects are closely related to a successful NF training in children with ADHD. In future studies, neurophysiological recordings could help to optimize and individualize NF training.

SIGNIFICANCE: The findings contribute to a better understanding of the mechanisms underlying NF training in children with ADHD. http://www.ncbi.nlm.nih.gov/pubmed/20843737


Distinct EEG effects related to neurofeedback training in children with ADHD: a randomized controlled trial.


In a randomized controlled trial, neurofeedback (NF) training was found to be superior to a computerised 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.

RESULTS: 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. http://www.ncbi.nlm.nih.gov/pubmed/19712709


EEG biofeedback of low beta band components: frequency-specific effects on variables of attention and event-related brain potentials.

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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=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.


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