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Elife. 2017 Sep 16;6. pii: e28974. doi: 10.7554/eLife.28974.

Direct modulation of aberrant brain network connectivity through real-time NeuroFeedback.

Ramot M[1], Kimmich S[1], Gonzalez-Castillo J[1], Roopchansingh V[2], Popal H[1], White E[1], Gotts SJ[1], Martin A[1].
Author information

Abstract

The existence of abnormal connectivity patterns between resting state networks in neuropsychiatric disorders, including Autism Spectrum Disorder (ASD), has been well established. Traditional treatment methods in ASD are limited, and do not address the aberrant network structure. Using real-time fMRI neurofeedback, we directly trained three brain nodes in participants with ASD, in which the aberrant connectivity has been shown to correlate with symptom severity. Desired network connectivity patterns were reinforced in real-time, without participants' awareness of the training taking place. This training regimen produced large, significant long-term changes in correlations at the network level, and whole brain analysis revealed that the greatest changes were focused on the areas being trained. These changes were not found in the control group. Moreover, changes in ASD resting state connectivity following the training were correlated to changes in behavior, suggesting that neurofeedback can be used to directly alter complex, clinically relevant network connectivity patterns.

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Eur J Neurosci. 2018 Mar;47(6):579-591. doi: 10.1111/ejn.13551. Epub 2017 Mar 27.

Positive effects of neurofeedback on autism symptoms correlate with brain activation during imitation and observation.

Datko M[1,2,3], Pineda JA[1,3], Müller RA[2].
Author information

Abstract

Autism has been characterized by atypical task-related brain activation and functional connections, coinciding with deficits in sociocommunicative abilities. However, evidence of the brain's experience-dependent plasticity suggests that abnormal activity patterns may be reversed with treatment. In particular, neurofeedback training (NFT), an intervention based on operant conditioning resulting in self-regulation of brain electrical oscillations, has shown increasing promise in addressing abnormalities in brain function and behavior. We examined the effects of ≥ 20 h of sensorimotor mu-rhythm-based NFT in children with high-functioning autism spectrum disorders (ASD) and a matched control group of typically developing children (ages 8-17). During a functional magnetic resonance

imaging imitation and observation task, the ASD group showed increased activation in regions of the human mirror neuron system following the NFT, as part of a significant interaction between group (ASD vs. controls) and training (pre- vs. post-training). These changes were positively correlated with behavioral improvements in the ASD participants, indicating that mu-rhythm NFT may be beneficial to individuals with ASD.

KEYWORDS:

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Neurophotonics. 2017 Jan;4(1):011003. doi: 10.1117/1.NPh.4.1.011003. Epub 2016 Aug 17.

Optical-imaging-based neurofeedback to enhance therapeutic intervention in adolescents with autism: methodology and initial data.

Liu N[1], Cliffer S[1], Pradhan AH[2], Lightbody A[1], Hall SS[1], Reiss AL[3].
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Abstract

Impaired facial processing may contribute to social dysfunction in certain individuals with autism spectrum disorder (ASD). Prior studies show that electroencephalogram-based and functional magnetic resonance imaging-based neurofeedback might help some individuals with ASD learn to modulate regional brain activity and thus reduce symptoms. Here, we report for the first time the feasibility of employing functional near-infrared spectroscopy (fNIRS)-based neurofeedback training in children with ASD. We developed a method to study physiological self-regulation of oxy-hemoglobin using real-time feedback. The paradigm is illustrated with initial data from four subjects who engaged in a facial-identity recognition training program during which an implicit reinforcement was given based on the participant's brain activity and behavioral performance. Two participants had a confirmed diagnosis of ASD, and the other two were typically developing (TD). One participant with ASD and one TD participant received real-feedback (real-FB) during the training, whereas the other two received sham-feedback (sham-FB). After five training sessions, the subjects who received real-FB showed more improvement in facial recognition performance compared with those receiving sham-FB, particularly in the participant with ASD. These results suggest fNIRS-based neurofeedback could enhance therapeutic intervention in children with ASD.

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Front Hum Neurosci. 2016 Jan 14;9:723. doi: 10.3389/fnhum.2015.00723. eCollection 2015.

Relative Power of Specific EEG Bands and Their Ratios during Neurofeedback Training in Children with Autism Spectrum Disorder.

Wang Y[1], Sokhadze EM[2], El-Baz AS[3], Li X[1], Sears L[4], Casanova MF[5], Tasman A[6].
Author information

Abstract

Neurofeedback is a mode of treatment that is potentially useful for improving self-regulation skills in persons with autism spectrum disorder. We proposed that operant conditioning of EEG in neurofeedback mode can be accompanied by changes in the relative power of EEG bands. However, the details on the change of the relative power of EEG bands during neurofeedback training course in autism are not yet well explored. In this study, we analyzed the EEG recordings of children diagnosed with autism and enrolled in a prefrontal neurofeedbacktreatment course. The protocol used in this training was aimed at increasing the ability to focus attention, and the procedure represented the wide band EEG amplitude suppression training along with upregulation of the relative power of gamma activity. Quantitative EEG analysis was completed for each session of neurofeedback using wavelet transform to determine the relative power of gamma and theta/beta ratio, and further to detect the statistical changes within and between sessions. We found a linear decrease of theta/beta ratio and a liner increase of relative power of gamma activity over 18 weekly sessions of neurofeedback in 18 high functioning children with autism. The study indicates that neurofeedback is an effective method for altering EEG characteristics associated with the autism spectrum disorder. Also, it provides information about specific changes of EEG activities and details the correlation between changes of EEG and neurofeedback indexes during the course of neurofeedback. This pilot study contributes to the development of more effective approaches to EEG data analysis during prefrontal neurofeedback training in autism.

J Autism Dev Disord. 2015 Dec;45(12):4084-100. doi: 10.1007/s10803-015-2523-5.

An Effective Neurofeedback Intervention to Improve Social Interactions in Children with AutismSpectrum Disorder.

Friedrich EV[1], Sivanathan A[2], Lim T[2], Suttie N[3], Louchart S[3,4], Pillen S[5], Pineda JA[5].
Author information

Abstract

Neurofeedback training (NFT) approaches were investigated to improve behavior, cognition and emotion regulation in children with autismspectrum disorder (ASD). Thirteen children with ASD completed pre-/post-assessments and 16 NFT-sessions. The NFT was based on a game that encouraged social interactions and provided feedback based on imitation and emotional responsiveness. Bidirectional training of EEG mu suppression and enhancement (8-12 Hz over somatosensory cortex) was compared to the standard method of enhancing mu. Children learned to control mu rhythm with both methods and showed improvements in (1) electrophysiology: increased mu suppression, (2) emotional responsiveness: improved emotion recognition and spontaneous imitation, and (3) behavior: significantly better behavior in every-day life. Thus, these NFT paradigms improve aspects of behavior necessary for successful social interactions.

KEYWORDS:

Appl Psychophysiol Biofeedback. 2014 Dec;39(3-4):237-57. doi: 10.1007/s10484-014-9264-7.

Neuromodulation integrating rTMS and neurofeedback for the treatment of autism spectrum disorder: an exploratory study.

Sokhadze EM[1], El-Baz AS, Tasman A, Sears LL, Wang Y, Lamina EV, Casanova MF.
Author information

Abstract

Autism spectrum disorder (ASD) is a pervasive developmental disorder characterized by deficits in social interaction, language, stereotyped behaviors, and restricted range of interests. In previous studies low frequency repetitive transcranial magnetic stimulation (rTMS) has been used, with positive behavioral and electrophysiological results, for the experimental treatment in ASD. In this study we combined prefrontal rTMS sessions with electroencephalographic (EEG) neurofeedback (NFB) to prolong and reinforce TMS-induced EEG changes. The pilot trial recruited 42 children with ASD (~14.5 years). Outcome measures included behavioral evaluations and reaction time test with event-related potential (ERP) recording. For the main goal of this exploratory study we used rTMS-neurofeedback combination (TMS-NFB, N = 20) and waitlist (WTL, N = 22) groups to examine effects of 18 sessions of integrated rTMS-NFB treatment or wait period) on behavioral responses, stimulus and response-locked ERPs, and other functional and clinical outcomes. The underlying hypothesis was that combined TMS-NFB will improve executive functions in autistic patients as compared to the WTL group. Behavioral and ERP outcomes were collected in pre- and post-treatment tests in both groups. Results of the study supported our hypothesis by demonstration of positive effects of combined TMS-NFB neurotherapy in active treatment group as compared to control WTL group, as the TMS-NFB group showed significant improvements in behavioral and functional outcomes as compared to the WTL group.

Philos Trans R Soc Lond B Biol Sci. 2014 Apr 28;369(1644):20130183. doi: 10.1098/rstb.2013.0183. Print 2014.

Neurofeedback training produces normalization in behavioural and electrophysiological measures of high-functioning autism.

Pineda JA[1], Carrasco K, Datko M, Pillen S, Schalles M.
Author information

Abstract

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.

Med Hypotheses. 2012 Dec;79(6):790-8. doi: 10.1016/j.mehy.2012.08.031. Epub 2012 Sep 20.

Self-regulation of brain oscillations as a treatment for aberrant brain connections in children with autism.

Pineda JA[1], Juavinett A, Datko M.
Author information

Abstract

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.

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Appl Psychophysiol Biofeedback. 2013 Mar;38(1):17-28. doi: 10.1007/s10484-012-9204-3.

Is EEG-biofeedback an effective treatment in autism spectrum disorders? A randomized controlled trial.

Kouijzer ME[1], van Schie HT, Gerrits BJ, Buitelaar JK, de Moor JM.
Author information

Abstract

EEG-biofeedback has been reported to reduce symptoms of autism spectrum disorders (ASD) in several studies. However, these studies did not control for nonspecific effects of EEG-biofeedback and did not distinguish between participants who succeeded in influencing their own EEG activity and participants who did not. To overcome these methodological shortcomings, this study evaluated the effects of EEG-biofeedback in ASD in a randomized pretest-posttest control group design with blinded active comparator and six months follow-up. Thirty-eight participants were randomly allocated to the EEG-biofeedback, skin conductance (SC)-biofeedback or waiting list group. EEG- and SC-biofeedback sessions were similar and participants were blinded to the type of feedback they received. Assessments pre-treatment, post-treatment, and after 6 months included parent ratings of symptoms of ASD, executive function tasks, and 19-channel EEG recordings. Fifty-four percent of the participants significantly reduced delta and/or theta power during EEG-biofeedback sessions and were identified as EEG-regulators. In these EEG-regulators, no statistically significant reductions of symptoms of ASD were observed, but they showed significant improvement in cognitive flexibility as compared to participants who managed to regulate SC. EEG-biofeedback seems to be an applicable tool to regulate EEG activity and has specific effects on cognitive flexibility, but it did not result in significant reductions in symptoms of ASD. An important finding was that no nonspecific effects of EEG-biofeedback were demonstrated.

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Appl Psychophysiol Biofeedback. 2010 Mar;35(1):63-81. doi: 10.1007/s10484-009-9120-3.

Neurofeedback outcomes in clients with Asperger's syndrome.

Thompson L[1], Thompson M, Reid A.
Author information

Abstract

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 (4-8 Hz)(2)/(13-21 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.

Appl Psychophysiol Biofeedback. 2010 Mar;35(1):13-23. doi: 10.1007/s10484-009-9102-5. Epub 2009 Aug 1.

The relative efficacy of connectivity guided and symptom based EEG biofeedback for autisticdisorders.

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Author information

Abstract

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 autisic symptoms. Different patterns of hyper- and hypo-connectivity have been identified with the use of quantitative electroencephalogray (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.

Appl Psychophysiol Biofeedback. 2010 Mar;35(1):39-61. doi: 10.1007/s10484-009-9095-0. Epub 2009 Jul 1.

Functional neuroanatomy and the rationale for using EEG biofeedback for clients with Asperger's syndrome.

Thompson L[1], Thompson M, Reid A.
Author information

Abstract

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.

J Child Psychol Psychiatry. 2007 Jan;48(1):3-16.

Annotation: neurofeedback - train your brain to train behaviour.

Heinrich H[1], Gevensleben H, Strehl U.
Author information

Abstract

BACKGROUND:

Neurofeedback (NF) is a form of behavioural training aimed at developing skills for self-regulation of brain activity. Within the past decade, several NF studies have been published that tend to overcome the methodological shortcomings of earlier studies. This annotation describes the methodical basis of NF and reviews the evidence base for its clinical efficacy and effectiveness in neuropsychiatric disorders.

METHODS:

In NF training, self-regulation of specific aspects of electrical brain activity is acquired by means of immediate feedback and positive reinforcement. In frequency training, activity in different EEG frequency bands has to be decreased or increased. Training of slow cortical potentials (SCPs) addresses the regulation of cortical excitability.

RESULTS:

NF studies revealed paradigm-specific effects on, e.g., attention and memory processes and performance improvements in real-life conditions, in healthy subjects as well as in patients. In several studies it was shown that children with attention-deficit hyperactivity disorder (ADHD) improved behavioural and cognitive variables after frequency (e.g., theta/beta) training or SCP training. Neurophysiological effects could also be measured. However, specific and unspecific training effects could not be disentangled in these studies. For drug-resistant patients with epilepsy, significant and long-lasting decreases of seizure frequency and intensity through SCP training were documented in a series of studies. For other child psychiatric disorders (e.g., tic disorders, anxiety, and autism) only preliminary investigations are available.

CONCLUSIONS:

There is growing evidence for NF as a valuable treatment module in neuropsychiatric disorders. Further, controlled studies are necessary to establish clinical efficacy and effectiveness and to learn more about the mechanisms underlying successful training.