INSIGHTS IN EEG VERSUS HEG AND RT-FMRI NEURO FEEDBACK TRAINING FOR COGNITION ENHANCEMENT

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ABSTRACT

Innovative research technologies in the neurosciences have remarkably improved the perception of brain structure and function. The use of several neurofeedback training techniques is broadly used for the memory and cognition augmentation as well as for several learning difficulties and AHDD rehabilitation. Author's objective is to review cognitive enhancement techniques with the use of brain imaging intervention methods as well to evaluate the effects of these methods in the educational process. The efficiency and limitations of neurofeedback training with the use of EEG brain imaging, HEG scanning, namely NIR and PIR method and fMRI scan including rt-fMRI brain scanning technique are also discussed. Moreover, technical and clinical details of several neurofeedback treatment approaches were also taken into consideration.

KEYWORDS

Cognition; EEG signal; fMRI; HEG; learning difficulties; memory; neurofeedback training; rehabilitation

1. INTRODUCTION

Neuroscience methods combined with cognitive sciences have gradually created a new principle in educational studies, in order to evaluate among others the influence in cognition [1]. Neuroscience is a field related to fields of neurology, physiology, and biology while the neuroscience conflict with education is related to the development of techniques for brain imaging and enhancing human brain performance during performing several cognitive functions. Research with the use of cognitive neuroimaging provides evidence for several brain function better perception. These functions better perception could be used in order to enhance educational methods related with complex processes underpinning speech and language, thinking and reasoning, reading, and mathematics.

Research methods blending neuroscience and educational perspectives involve the use brain imaging tools to evaluate cognitive functions and enhance educational results in practice. Considering the fact that genetic factors and brain physiology affect brain function, cognitive abilities and mathematical perception could be evaluated within this frame with the use of imaging techniques. Neurofeedback is an approach for non-invasive modulation of human brain activity in order to manage mental disorders and enhance cognitive performance. The most common neurofeedback training techniques are implemented with EEG brain signal implementation. Nevertheless, neurofeedback training session is implemented as well with the use several brain imaging techniques besides EEG, like real-time functional magnetic resonance imaging (rtfMRI) or Hemoencephalography (HEG). Namely for the most frequently used neurofeedback technique 2 to 4 surface electrodes are used to change the amplitude or speed of specific brain waves in particular brain locations to treat ADHD, anxiety, and insomnia [2]. The Hemoencephalographic (HEG) neurofeedback provides feedback on cerebral blood flow to treat

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migraine [3], while the most recent type of neurofeedback, the functional magnetic resonance imaging (fMRI) is used to regulate brain activity based on the activity feedback from deep subcortical areas of the brain [4]. The aim of these neurofeedback training approaches is to modify brain activity in a different way which is based on particular neurological measures according to the used method.

2. EDUCATIONAL NEUROSCIENCE

Educational neuroscience is blending scientific fields like neuroscience, cognitive sciences, and education. Educational neuroscience methods focus on accessing real-time information about the brain in order to enhance cognitive functions like language, speech, emotion, consciousness, attention, memory, and other higher cognitive functions [5] is involved with the use of neuroscience-based techniques in order to enhance cognitive function. Neuroenhancement focus in the human brain and nervous system, altering its properties to increase performance for specific cognitive functions [6].

Research within the frame of Neuroeducation aims to enhance the relation between education and neuroscience, while the ability of the brain to learn is investigated within the context of education. Research design and methods in educational neuroscience involve neuroscientific tools such as brain image technologies to investigate cognitive functions and inform educational practices. The study of various aspects of neuroscience which relate to the task at hand aims to provide improved learning and new teaching methods. Educational neuroscience, also called neuroeducation, refers to educators and neuroscience researcher's collaboration in order to improve both the education and neuroscientific research. It is a recent interdisciplinary scientific field that brings together researchers of developmental cognitive neuroscience, educational psychology, technology, and theory as well as other related disciplines. Researchers of educational neuroscience review the neural mechanisms of reading, numerical cognition, attention in combination to learning difficulties including dyslexia, dyscalculia, and ADHD.

3. NEUROFEEDBACK TRAINING

Neurofeedback is a training technique that helps individuals learn how to self-regulate brain activity with the use of neurological feedback provided by sensory devices. During a neurofeedback training, the participant has to control and modify the amplitude, frequency or coherence of the electrical signal. Neurofeedback session includes several types of training like EEG neurofeedback training, HEG neurofeedback, and real-time fMRI neurofeedback training. These neurofeedback training approaches modify brain activity in a different way which is based on particular neurological measures. A number of related research provides evidence that neurofeedback training is efficiently used in order to improve neuropsychological disorders, improve cognitive efficiency, and enhance brain functions in healthy individuals [7].

3.1 NEURO FEEDBACK TRAINING TYPES

In order enhance several cognitive functions or improve brain disorders several types neurofeedback training methods depending on treatment case. For instance, slow corticalpotential neurofeedback (SCP-NF) improves the direction of slow cortical potentials to treat ADHD, epilepsy, and migraines [8]. Additionally, low energy neurofeedback system (LENS)supplies a weak electromagnetic signal to alter the patient's brain waves while they aremotionless with their eyes closed. This neurofeedback method is useful for traumatic brain injury, ADHD, insomnia, fibromyalgia, restless legs syndrome, anxiety, depression, and anger treatment [9]**.** Moreover, live Z-score neurofeedback is used to treat insomnia. It introduces the continuous comparison of variables of brain electrical activity to a systematic database to provide continuous feedback [10].

Moreover, low-resolution electromagnetic tomography (LORE-TA) includes the use of 19 electrodes to monitor phase, power, and coherence. This neurofeedback technique is used to deal with addictions, depression, and obsessive-compulsive disorder [11]. Nevertheless, these neurofeedback training techniques are beyond of this review objective, therefore, they are not further analyzed.

3.2 EEG NEUROFEEDBACK TRAINING

Within neurofeedback process, participants receive feedback derived from a number of sensors or a specified device which record brain activity. Neurofeedback is a form of behavioral intervention in terms of improving the skills in the area of intelligence and brain activity. Neurofeedback training targets on changing the brain activity in both healthy and mentally disabled people [12].The most common type of neurofeedback training is EEG neurofeedback, where electrodes are placed on a person's scalp, detect and evaluate potential brain wave abnormalities, and control the trainee in order to improve his brain activity consciously.

3.3 EEG NEUROFEEDBACK TRAINING PROTOCOLS

Neurofeedback treatment protocols mainly focus on the alpha, beta, delta, theta, and gamma treatment or a combining the wave's ratio namely, alpha-theta ratio, beta-theta ratio, etc. However, protocols like alpha, beta, theta, and alpha-theta ratio are mainly used for cognition enhancement. Alpha training is mostly used for stress and anxiety reducing, for memory and mental performance enhancement, and for brain injuries treatment [13]**.** According to SMR-low Beta protocol, EEG neurofeedback training focus on normalizing abnormal EEG frequencies, decreasing Theta ratio and increasing sensory motor rhythm (SMR) activity (10–13 Hz) in order to reach an improved cognitive performance. Beta training is used to improve concentration, computational performance, cognitive processing, reading ability, obsessive-compulsive disorder (OCD) symptoms, and insomnia. Additionally, neurofeedback training technique is used for healthy individuals in order to control Alpha-Theta waves providing an essential enhancement to the brain ability. Alpha-theta training is commonly used for reducing stress effect, while it increases creativity, relaxation, and musical performance. Alpha training is conducted within eyes-closed condition in order to increase theta ratio to alpha ratio with the use of auditory feedback. Theta brain waves are related to a number of brain activities such as memory, emotion, creativity, and meditation. Theta treatment is mainly used to reduce anxiety, depression, and ADHD. Gamma waves are related to cognitive processing and memory. Gamma training is used for cognition enhancement, mental sharpness improvement, information processing augmentation, problem-solving tasks and short-term memory improvement [13].

EEG neurofeedback training is considered to be a safe and painless method, while sensors are placed on the head and record the brain activity without interfering with this procedure. A typical EEG Neurofeedback training session is about participants to be involved with a video game while the brain waves derived from the sensors connected to their brain is recorded. During the game, the mind waves are controlled by means of an amplifier and a computer so the needed feedback to be provided to the trainee. Gradually the mind responds to the signs of the continuous feedback in order to enhance and stabilize the participant state of mind in an improved state in terms of attention and self-regulation. The brain activity waves, although they are unconscious processes within this procedure, are set under individual's control. EEG neurofeedback research mainly focuses on the improvement of the symptoms cognitive disorders like Attention Deficit Activity Disorder (ADHD) or several learning disabilities.

3.4 HEG NEUROFEEDBACK

Hemoencephalography (HEG) is a neurofeedback method where the trainee regulates consciously the cortical blood flow. This technique is based on the idea that neurological feedback provided by the HEG device trainee could consciously control the unconscious blood flow process. Normally it would be impossible to detect, HEG neurofeedback device provides information about blood flow whether it is high or low in certain regions. HEG is considered to be an effective method for alleviating unwanted psychological impairment stemming from poor blood flow. Both the test of variables of attention (TOVA) which is designed to assess cognitive function and Spect scan for measuring the cortical blood flow are used in order to perform HEG neurofeedback training. HEG neurofeedback training method includes NIR (near infrared) and PIR (passive infrared) techniques. Specifically, near-infrared HEG is designed to measure changes in oxygen levels within the blood and passive infrared HEG incorporates with the measurement of cortical heat and blood oxygen levels [8].

3.5 FMRI NEUROFEEDBACK TRAINING

Brain imaging fMRI scanners are designed to provide "real time" instantaneous feedback, thus real-time fMRI neurofeedback is used to detect determine abnormal neural connectivity and provide feedback to the trainee in order to chance it. Within the use of fMRI neurofeedback technique, a non-invasively neural functioning in real time analysis is provided. The technique is used for diagnosing diseases, monitoring the severity, and tracking the efficacy of therapeutic interventions for mental illnesses such as ADHD, anxiety, and depression [4].

Specifically, the trainee could learn to control unconscious processes within the brain such as the activation of certain neural correlates associated with a disorder. This method is based on the brain's ability to change itself or else self-directed neuroplasticity. Trainee lie under the rtfMRI scanner in his brain activity could be evaluated in real time. Specifically, feedback regarding regional activation is provided about the brain activity and whether is increasing or decreasing in problematic areas. In the case that the activity is decreasing in problematic areas, the feedback is a "green light" on a computer screen signaling the participant that he is doing the right thing. In the case that activity is increasing in problematic areas, the feedback provided is a "red light" on the computer program noticing the trainee that he is doing the wrong thing. With repeated practice, the trainee would control the ability to consciously regulate his unconscious brain activity process.

3.6 NEUROFEEDBACK AND BRAIN TRAINING LIMITATION

EEG Neurofeedback involves a brain–computer interface that leads users to learn how to control their cortical oscillations. EEG Neurofeedback has broadly used brain disorders treatment, nevertheless there no sufficient evidence in regards to the efficacy on brain functions. However, while EEG has superior temporal resolution compared to standard fMRI, poor spatial resolution limits the clinical utility of EEG [14]. Techniques like electroconvulsive therapy, vagus nerve stimulation, deep brain stimulation, and transcranial magnetic stimulation or transcranial direct current stimulation, are also proposed for the treatment of brain disorders while producing clinical change via altered neuroplasticity. Each of these methods has potential benefits as well as limitations related to spatial resolution or by their invasive nature [15].

4. NEUROFEEDBACK TRAINING AND COGNITION

Neurofeedback training is based on implicit and nonconscious learning and conditioning.The executive system is a cognitive system in psychology that controls cognitive processes alsoreferred as the executive function, supervisory attentional system, or cognitive control. These

functions are mainly located in prefrontal areas of the frontal lobe and they related with processes like planning, working memory, attention, problem-solving, reasoning, inhibition, mental flexibility, multi-tasking, initiation and monitoring of actions [16].

Zotev et al. combined two approaches of simultaneous multimodal rtfMRI and EEG neurofeedback (rtfMRI–EEG-nf). RtfMRI and EEG-nf were applied for the training of emotional self-regulation in healthy participants while dealing with a positive emotion induction task based on retrieval of pleasant autobiographical memories. This case study reviled the feasibility of simultaneous self-regulation of both hemodynamic (rtfMRI) and electrophysiological (EEG) activities of the human brain. In addition, evidence related to enhanced cognitive therapeutic approaches for major neuropsychiatric disorders, particularly depression were suggested [17].

In Ros et.al, study healthy participants, were examined during performing attentional tasks in order to check the plastically of distinct fMRI networks after reduction of alpha rhythm versus a sham-feedback condition. In comparison to sham-feedback, EEG neurofeedback technique induced an increase of connectivity within regions of the salience network linked within intrinsic alertness (dorsal anterior cingulate). These findings suggest a neurobehavioral relation with brain's exquisite functional plasticity as well as for a temporally direct impact of EEG neurofeedback technique on a basic cognitive control network [18].

Mckendrick et al. evaluated the impact of working memory training on brain function and behavior. Participants were monitored with the use of near-infrared spectroscopy (NIRS) during their involvement with a dual verbal-spatial working memory task. Subjects were either assigned to an adaptive state whose working memory load was adjusted in accordance with performance, and others to a yoked condition whose working memory load was determined based on the performance of trainees in the adaptive state. Changes in cerebral hemodynamics in reference to left DLPFC and right VLPFC were noticed to be associated with time participants spent in training. The results of the comparison between adaptive and yoked training suggested differences in the rostral prefrontal cortex. These findings were interpreted in terms of decreased proactive interference, increased neural efficiency, reduced mental workload for stimulus processing, and increased working memory capacity with training [19].

Strenziok et al. examined the effects of extensive video game training on performance, white matter integrity, and brain functional connectivity in healthy older adults. Video game training was used to associate the far transfer with altered attentional control demands mediated by the dorsal attention network and trained sensory cortex. Cognitive performance, diffusion-derived white matter integrity, and functional connectivity of the superior parietal cortex were evaluated both before and after the neurofeedback training protocol implementation. Findings suggested that both auditory perception and visuomotor-working memory training also lead to changes in functional connectivity between superior parietal cortex and inferior temporal lobe [20].

Toomim et.al., suggests that that NIR HEG training can consciously enhance regional cerebral oxygenation to specific areas of the brain and result in increased performance on cognitive tasks. Specifically, after only ten 30-minute sessions of HEG brain exercise training, participants facing several neurological disorders showed increases in attention and decreases in impulsivity to within normal levels [8].

3.7 NEUROFEEDBACK TRAINING IMPACT IN ADHD

People with ADHD (attention-deficit/hyperactivity disorder) are noticed to have decreased blood flow to the prefrontal cortex region. The use of HEG neurofeedback technique in order to increase blood flow to this region is suggested. Learned enhancement of EEG frequency components in the lower beta range is suggested to be effective with ADHD symptoms.

According to Egner et al., study neurofeedback protocols was applied to healthy volunteers in order to evaluate the impact on behavioral and electrocortical attention measures. Operant enhancement of a 12-15Hz component was linked to a reduction in commission errors and improved perceptual sensitivity in the case of a continuous performance task (CPT). On the contrary, the opposite relation was noticed in the case of 15-18Hz enhancement. Both 12-15Hz and 15-18Hz enhancement were related to notable increases in P300 event-related brain potential amplitudes in an auditory oddball task [21].

3.8 NEUROFEEDBACK TRAINING IMPACT IN MATHEMATICS COGNITION

Hashemian et al., an approach using neurofeedback enhance the significance of treatment in learning disorders. In their study, third grade of primary school children was selected separated into two equal groups while the first group which received neurofeedback treatment while the other group received non-real neurofeedback treatment (sham or placebo). The two groups were matched for age, education, sex and degree of intelligence and mathematics disorder Neurofeedback treatment was performed based on enhancement of beta/theta ratio in CZ region. The comparison between real and sham groups showed that the effect of real neurofeedback therapy was significant comparing to the sham group. Statistical analysis showed that neurofeedback improves mathematic performance in boys while the training efficiency was noticed to be high even one year after treatment [22].

4. DISCUSSION

Although neurofeedback training has widely been used in order to enhance cognition, neurofeedback training for mathematical thinking enhancement has been shortly utilized. Taken into consideration the pros and cons of several neurofeedback techniques and after a literature review and the generalized methodological outline, a specified research framework based on theoretical and experimental research models about mathematical thinking is suggested. Author's future work leans towards an algorithmic thinking enhancement model in order to overall promote adaptability intelligence and learning. Algorithmic problem solving requires some abstract thinking and coming up with a creative solution. Considered the most complex of all intellectual functions, algorithmic problem solving has been suggested as a higher-order cognitive process that requires the modulation and control of more routine or fundamental skill. The procedure of enhancing algorithmic problem-solving ability is central to the higher-order cognitive skills (HOCS) [23]. Thereafter related work in reference with cognition enhancement are studied, two neurofeedback protocols namely Alpha-Theta and SMR-low Beta protocol are proposed for reasoning and algorithmic thinking enhancement. During the proposed method pilot phase, both the Alpha-theta and SMR-Low Beta neurofeedback training protocol are implemented in the case study participants. During neurofeedback training and algorithmic thinking evaluation the electrical brain signal was recorded for both neurofeedback and non-neurofeedback group. EEG brain scanning implemented during the pilot study suggest the qualitative difference between neurofeedback and non-neurofeedback trained group electrical activity while dealing with the same mental task. In Figure 1, the electrical signal in the case of a neurofeedback trained participant is presented during the pilot implementation of SMR-Low Beta protocol. Additionally, in Figure 2 the electrical activity in the case of a non-neurofeedback evaluated participant while being in the same mental stage is presented.

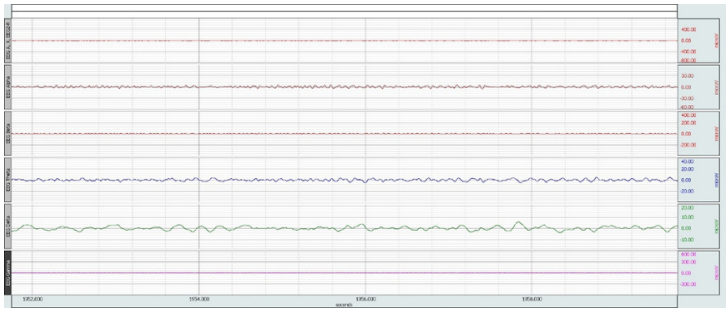

Figure 1: EEG Signal Recording During Neurofeedback Training

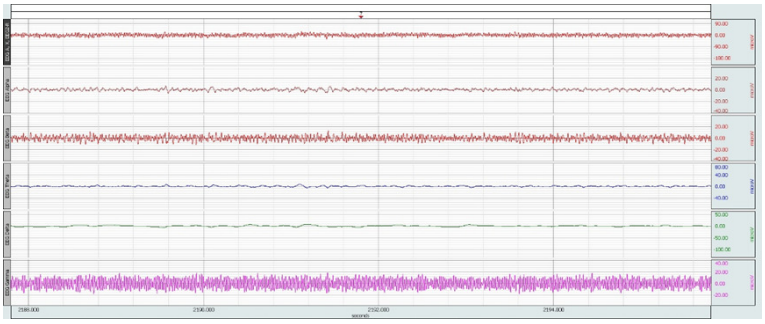

Figure 2: EEG Signal Recording During a Non-Neurofeedback Training

Additional research in the frame of the above directions are necessary in order to evaluate quantitatively the difference between the neurofeedback and non-neurofeedback pilot trained participants.

5. CONCLUSION

In this paper, clinical applications of neurofeedback training, various protocols of treatment and the HEQ and fMRI neurofeedback methods in terms of cognition enhancement. Several related case studies were analyzed in order to evaluate the effectiveness of each neurofeedback training approach. Neurofeedback has widely been used on individuals with educational abnormalities and it's another step for further discussion in cognitive science. Nevertheless, neuroimaging studies of mathematical learning disabilities are still rare but dyscalculia is an area of increasing interest for neuroscience researchers. Author's future work leans towards neurofeedback training implementation in the case of participants facing mathematical disorders in order to strengthen algorithmic thinking abilities.

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