Neurofeedback and ADHD

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Abstract—ADHD is a neurodevelopmental disorder across children population and much research is being conducted to find the best ADHD treatment. Neurofeedback (NF) is widely used for the treatment of ADHD, thus such ADHD cases will be reviewed in this study. As an introduction, a short overview of the definition of ADHD and Neurofeedback, as well as the history of neurofeedback in ADHD will be given. The main part of the paper will present a literature review of neurofeedback in ADHD while mentioning the effects of this treatment. The review will give emphasis on studies using randomised control trials. Results and evaluation of NF interventions among other treatments are to be discussed in the conclusion, showing that NF is a quite promising intervention method for on ADHD.

Keywords—neurofeedback, NF, EEG biofeedback, ADHD, randomized control trial

1 Introduction

1.1 Defining ADHD and neurofeedback

According to DSM-V, ADHD is a neurodevelopmental disorder defined by impairing levels of inattention, disorganization, and/or hyperactivity-impulsivity [6]. There are three subtypes of ADHD: ADHD Predominantly inattentive type (ADHDin), ADHD Predominantly hyperactive/impulsive type (ADHDhi), and ADHD Combined type (ADHDcom), where individuals meet criteria for both hyperactivity/impulsivity and inattention. The disorder often persists into adulthood, with resultant impairments in social, academic and occupational functioning [5]. Significant increases in the prevalence of ADHD from 8.5% to 9.5% ($p<.01$), in US children, aged from 3 to 17 years old, were present from 2009–2011 to 2015–2017 [9].

There are many available pharmacological and non-pharmacological treatments for ADHD [1]. Neurofeedback is one of the non-pharmacological treatments that will be discussed in this paper.

Neurofeedback (NF) is a non-invasive intervention strategy for a variety of conditions, such as brain-based disorders. It is mostly used for the treatment of attention deficits and for improving academic performance [40]. It does not include medication, though it can be used along with medication, according to the physician's guidelines. Other names for neurofeedback (NF) are Electroencephalographic (EEG) biofeedback, and Neurotherapy. The neurofeedback equipment involves NF software and NF hardware, such as a Brain-Computer Interface (BCI), an EEG cup and peripheral devices.

1.2 History of neurofeedback in ADHD

Lubar was the first to apply EEG biofeedback in a hyperkinetic child in 1976 and found improvements as the SMR application enhanced motor inhibition [18]. NF aims at improving the self-regulation of brain activity using a brain–computer interface. Numerous studies have analyzed the effects of neurofeedback on ADHD subjects.

2 Neurofeedback effects on ADHD

Studies have demonstrated that neurofeedback reduces inattention, impulsivity, and hyperactivity that are the hallmarks of ADHD and is as effective as stimulant drugs in controlling ADHD symptoms [35]. Some of these studies are listed below.

Lubar et al., evaluated 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 [19]. Three individual studies showed remarkable results after neurofeedback sessions. The first study presented major improvement in T.O.V.A. scores, as the participants managed to decrease the theta brainwave activity. The second one reported improvement in parent ratings following neurofeedback training; and the last one revealed significant progress in WISC-R tests following neurofeedback sessions.

Leins et al., [37] indicated that the clinical effects of neurofeedback for ADHD remain stable six months after treatment. Both neurofeedback groups, the slow cortical potentials (SCP) and the Theta/Beta group, showed improvement in behavior, attention and IQ tests, and no major differences between the two groups were noted. The study strongly supports a lasting and positive effect of neurofeedback on ADHD.

Gevensleben et al., [15] used "SAM" ("Self-regulation and Attention Management"), a neurofeedback program, that they developed for neurofeedback training and "Skillies", a German learning software, for attention skills training through visual and auditive perception exercises. The result of a combined neurofeedback training (theta/beta training, SCP training) on the resting EEG was studied in children with ADHD in comparison to an attention skills training as control. EEG measures recorded at baseline as well as EEG parameterization led to the clinical outcome that not all trained EEG parameters can change the resting EEG. As a result, further research is needed concerning the choice of the treatment protocol and the number of sessions according to each ADHD case.

Gevensleben et al., [16] also evaluated the effectiveness of NF to children with ADHD through a randomized control study using computerized attention skills training (AST) as a control condition. The outcome was that the rate of responders of the NF group (about 52%) was superior to the control condition group (about 29%).

Arns and colleagues [26] reviewed that hyperactivity is less likely to be treated among ADHD sufferers and concluded that neurofeedback treatment for ADHD can be considered “Efficacious and Specific” level 5 with a high Effect Size (ES) for inattention and impulsivity and a medium ES for hyperactivity.

Lansbergen et al., [27] tested the feasibility and safety of using a double-blind placebo feedback-controlled design study. They explored the primary effect of 30 individualized EEG-neurofeedback training sessions in fourteen children with ADHD, some of which were also treated with medication. The study proved to be safe, as EEG-neurofeedback and placebo feedback did not seem to cause serious side effects, such as adverse reactions or sleeping disorders. The study was also “feasible” because placebo neurofeedback training was used as a control condition successfully.

Lofthouse et al., [29] investigated the effectiveness of NF for ADHD children, based on the results and methodologies of 14 published studies. The results of the studies that used the theta/beta NF with a unipolar-electrode placement at the Cz location (Figure 1), showed a medium ADHD Effect Size (ES) of d = 0.69, assuming that NF for pediatric ADHD can be currently considered as “probably effective”.

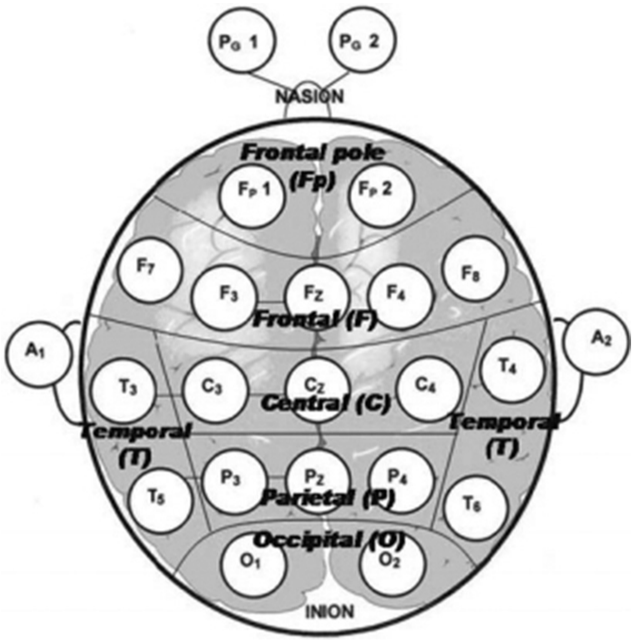

Fig. 1. Scalp placement and labels for Electrodes used in the International 10–20 system [33]
Note: Cz location is in the center. Adapted from “The Psychological and Neurological Bases of Leader Self-Complexity and Effects on Adaptive Decision-Making,” by Sean T. Hannah, Pierre A. Balthazard, David Waldman, Peter L. Jennings, and Robert Thatcher, 2007, Journal of Applied Psychology, 98(3). (https://doi.org/10.1037/a0032257) Copyright 2003 by the American Psychological Association.

The American Academy of Pediatrics [5] announced EEG Biofeedback as "Best Support" (Level 1) and as an effective stand-alone intervention for Attention and Hyperactivity Behaviors. "Best Support" indicates that the AAP has found that EEG biofeedback is a top-level treatment for Attention and Hyperactivity Behaviors, such as ADD/ADHD, thus should be recommended as a primary option.

Steiner et al., [28] investigated the results of an in-school Neurofeedback training on ADHD children, throughout their randomized control study. The in-school computer attention training intervention used neurofeedback or cognitive training (CT) and was administered to 7 to 11-year-old children with attention-deficit/hyperactivity disorder (ADHD). Neurofeedback training in the present study considerably exceeded the results of cognitive training, as improvements in ADHD symptoms sustained at the 6-month follow-up of the neurofeedback group than the other participants did.

Boyd et al., [41] performed a trial of EEG biofeedback training in the school setting of the Converse County School District #1 in Douglas, Wyoming. The experiment involved six male students, aged from 13 to 15 years old, diagnosed with ADHD, who were trained with EEG biofeedback sessions. Five students performed 20 EEG sessions and one performed 9 EEG sessions due to other health issues. EEG electrode placement was at the Cz location (Figure 1). The outcome showed improvement in combined WISC-III digit span subtest, TOVA inattention scale, and TOVA impulsivity scores for five of the six students, resulting in a positive outcome for at least 80% of the subjects.

Vernon et al., [12] reviewed studies that have utilized neurofeedback as an intervention for children with ADHD. They pointed out that children with ADHD have an unusual pattern of EEG activity and this explains why EEG analysis has revealed that up to 80% of children with ADHD exhibit abnormalities [31]. The greater the level of EEG abnormalities, the more the individual exhibits behavioral problems [7]. As a consequence, the best intervention for the treatment of these EEG abnormalities is EEG neurotherapy practice, since they believe that the main cause of ADHD is being treated in that way.

Patrick [14] tested if a 15 session photic-driven electroencephalograph training procedure could regulate brainwave activity and improve cognitive function in 25 ADHD children, aged from 8 to 14 years old, partly under medication and with limitation to ADHD medication for at least 8 hours before testing. 10 subjects were part of a control group. During the experiment, attention, impulsivity and scholastic achievement were measured. The results of the experimental group showed major improvement in gaining attention and controlling impulsivity. In contrast, the control group did not mark any changes in any measure. Apart from the 15 EEG training sessions, subjects had EEG measurements while they were doing the T.O.V.A. test. This provided important EEG feedback, as 67% of the participants increased variability in theta activity, 72% increased variability in beta activity and 50% increased variability in SMR, though the exact time they increased beta or decreased theta in response to the cognitive task is vague.

Clarke et al., [7] compared the EEG brainwave activity of two ADHD subtypes: 1) the Attention-Deficit/Hyperactivity Disorder of the Combined Type (ADHDcom) and 2) the Attention-Deficit/Hyperactivity Disorder of the Predominantly Inattentive Type (ADHDin), as well as the control group participants. The participants were children aged between 8 and 12 years old. Measurements of the delta, theta, alpha and beta activities through the EEG equipment witnessed that higher levels of theta and lower levels of alpha and beta were the results of both ADHD groups, but not the control group. High theta and low beta levels are generally noted in ADHD subjects, in many studies. EEG monopolar recordings also showed differences between the results of children with Attention-Deficit/Hyperactivity Disorder of the Predominantly Inattentive type and those of the Combined type, while they were on the same EEG procedures. These differences between the subtypes show that the disorder has different grades of severity among ADHD children.

Positive changes after twenty EEG Biofeedback sessions and Cognitive Retraining were reported in individuals with Attention Deficit Hyperactivity Disorder according to Tinius and Tinius [34]. The results revealed remarkable improvement in sustained attention and response accuracy, as compared to the control group.

Alhambra et al., [23] stated that EEG Biofeedback is a good option for ADD/ADHD treatment. This came out from the positive feedback of the questionnaires that 31 out of 36 ADHD participants filled upon completion of a series of EEG biofeedback sessions, resulting in 86% success. The remaining 5 participants showed either no improvement or indicated uncertainty regarding improvement after treatment.

Arns et al., [24] conducted a meta-analysis on the Theta/Beta ratio (TBR) in ADHD and found a correlation between the higher TBR level and the occurrence of ADHD. The participants were ADHD and non-ADHD subjects, aged 6–18 years old and TBR data was collected from the Cz location (Figure 1), with their eyes open. The findings showed the Effect Size (ES) was 0.75 for the group aged from 6 to 13 years old and 0.62 for the group aged 6 to 18 years old. The decline of ES upon age could not be fully justified, thus contradictions were raised for the reliability of this measure. As a result, nor an elevated TBR can be considered as a reliable measure for the assessment of ADHD, but it can only be a prognostic tool for the time being, according to the authors.

On the contrary, Arnold et al., [21] suggested that high theta–beta ratio (TBR) should be set as an inclusion criterion on future samples, especially if theta–beta downtraining is used as an EEG treatment, to practice brain activity likewise Monastra [38],[39],[40]. Among other inclusion criteria, they suggested that the ADHD participants should age between 6–12 years old and abstain from psychotropic medication that could affect the results. They also noted the significance of NF-sham along with the active NF, throughout their Randomized Clinical Trial that lasted 2 years. 34 ADHD subjects, out of 39 that were initially selected, completed a task of 40 EEG sessions. Participants took part in the treatments twice a week and gradually participated 3 times per week, leading to the conclusion that NF-sham proved to be useful and did not prevent retention.

Bresnahan et al., [32] examined the relevance between age-related changes in quantitive EEG activity in a group of ADHD subjects aged from 6 to 42 years old. Twenty-five children, 25 adolescents and 25 adults diagnosed with ADHD, as well as an equal number of ADHD-free participants (as a control group), took part in the study. During the EEG procedure, subjects were required to fixate on a cross on a computer screen for 2 minutes, without excessive blinking. The results showed that all ADHD groups showed a higher Theta/Beta Ratio activity than the normal control group did, which complies with literature. There was a decrease in the theta/beta ratio upon age though, which is a positive outcome as TBR downtraining is the key to ADHD management.

Janssen et al., [36] conducted a randomized control trial to investigate the effects of neurofeedback (NF), methylphenidate (MPH) and physical activity (PA) on EEG power spectra in children with ADHD. 112 children with ADHD, aged from 7 to 13 years old were recruited in this trial. The EEG power spectra measures were done during eyes open (EO), eyes closed (EC) and while task (effortful) conditions. Both NF and MPH medication treatment resulted in reductions in theta power from pre- to post-intervention during the EO resting condition, compared to the PA group. In conclusion, NF gives positive feedback and it is advised that NF protocols should train solely theta activity, both at rest and while performing tasks, in children with high theta activity.

Arns et al., [25] claimed that NF is distinguished among other ADHD treatments throughout (1) semi-active, (2) active, and (3) placebo-control group studies. A meta-analysis of semi-active control studies by Arns et al. [26] found that neurofeedback resulted in large and clinically relevant effect sizes for inattention and impulsivity and a medium effect size for hyperactivity. Moreover, RCTs performed at a follow-up NF treatment 6 months or 2 years after the initial NF treatment, demonstrated that the effects did not disappear with time, and there was a tendency for further improvement across time for hyperactivity/impulsivity.

Active studies found comparable effects of neurofeedback and methylphenidate for measures of inattention, impulsivity and hyperactivity. Last but not least, placebo-controlled studies, showed that NF group patients resulted in decreased hyperactivity/impulsivity in comparison to the control group [27].

Jiang and Johnstone [17] stated that the use of the neurocognitive training resulted in reduced AD/HD symptoms and improvement in social behavior for a group of five AD/HD children in China. A combination of two interventions, cognitive and neurofeedback training, were used for improving the behavior of children with AD/HD with success and full acceptance from the parents. Results indicated that each participant was able to produce a higher level of the desired psychological state after the completion of the experiment.

3 Neurofeedback combined with other treatments for ADHD

Neurofeedback accompanied by other methods can contribute to emotional balance and metacognitive development. For example, neurofeedback in conjunction with training in metacognitive strategies has been effective in students with ADD [22], since attention can be trained as a metacognitive and conscious process. Moreover, mindfulness thinking exercises have been found to enhance internal attention [3].

Immersing virtual reality (VR) is applicable to neurofeedback for the rehabilitation of inattention and impulsiveness, as VR was found to be effective in reducing inattention and impulsiveness levels [8]. VR offers attractive, useful, and promising tools that in combination with various strategies can improve emotional intelligence skills in children and individuals with ADHD and other special educational needs [11]. Social skills training is important for the emotional adjustment of children with ADHD and generally of children with special educational needs. In specific, improvement of emotional intelligence, that is identifying, understanding and expressing emotions has been found effective for these groups of children [2].

Computer based applications, as well as mobile applications, have gained popularity within the special needs community. Both are configured as powerful teaching tools and there are plenty attention training apps available for special education [4],[20].

4 Conclusion

Clinical observation notes that if ADHD is left untreated, inattention and impulsivity will remain in adulthood, while hyperactivity is likely to decline upon aging [32], [30].

ADHD sufferers, if treated with medication and/or behavior therapy, will gain some positive results but will relapse as soon as the treatment is discontinued [1]. Neurofeedback has positive results on ADHD, especially on inattention and impulsivity, as it is confirmed by the large Effect Sizes (ES) of NF treatment for inattention and impulsivity but medium ES for Hyperactivity [32]. Patients should do a follow-up neurofeedback treatment from 6–12 months after completing the initial NF treatment to maintain these results. Hyperactivity is not likely to be completely treated by NF but will decrease upon age [25]. Researchers are encouraged to practice NF-sham along with active NF throughout randomized clinical trials for trustworthy results [21]. It is recognized by the literature that NF plays an important role in the non-pharmacological treatment of ADHD. Such non-pharmacological treatments are also a good option for parents who are opposed to medication approaches for their ADHD children, especially in youth ADHD [17].

In ADHD assessment, measuring the EEG brain activity, especially in Cz location (Figure 1), could have a prognostic value [24], as children and adolescents with ADHD have generally reported an increase in theta activity [10] and a decrease in beta activity [13], compared with normal controls. EEG measurements, such as the theta/beta ratio cannot stand alone for an ADHD diagnosis though, but only as a part of a clinician's diagnosis.

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