



HAL
open science

Comparative efficacy of neurofeedback, tDCS, and TMS: The future of therapy for adults with ADHD. A systematic review and meta-analysis

Margaux Courrèges, Marie Hoareau, Carole Levenes, Hassan Rahioui

► **To cite this version:**

Margaux Courrèges, Marie Hoareau, Carole Levenes, Hassan Rahioui. Comparative efficacy of neurofeedback, tDCS, and TMS: The future of therapy for adults with ADHD. A systematic review and meta-analysis. *Journal of Affective Disorders*, 2025, 388, pp.119585. <10.1016/j.jad.2025.119585>. <hal-05390975>

HAL Id: hal-05390975

<https://hal.science/hal-05390975v1>

Submitted on 2 Dec 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Copyright - All rights reserved

Comparative efficacy of neurofeedback, tDCS, and TMS: The future of therapy for adults with ADHD. A systematic review and meta-analysis

Margaux Courrèges [a,b*](#), Marie Hoareau [a](#), Carole Levenes [b,1](#), Hassan Rahioui [a,1](#)

[a](#) GHU Paris Psychiatry & Neurosciences, 1 rue Cabanis, 75014 Paris, France

[b](#) CNRS, INCC, 45 rue des Saints-Pères, 75006 Paris, France

* Corresponding author.

E-mail address: margaux.courreges@ghu-paris.fr (M. Courrèges).

[1](#) These authors have contributed equally.

Received 13 January 2025; Received in revised form 26 May 2025; Accepted 3 June 2025

ABSTRACT

Background: ADHD is a prevalent neurodevelopmental condition worldwide. While therapeutic approaches continue to evolve, clinical considerations for adult patients remain underexplored. Recent approaches such as neurofeedback, tDCS, or rTMS, have emerged, requiring clarification of therapeutic protocols need to assess their relevance and efficacy.

Methods: a systematic search of PubMed, Web of Science, Cochrane Library, Ovid and ScienceDirect databases was performed. A total of 1747 articles were extracted and inclusion and exclusion criteria were applied to screen satisfactorily. Eighteen articles were selected for detailed analysis.

Results: tDCS and rTMS showed the most robust methodological designs among the studies analyzed. TDCS seems to be effective with anode at F3 and cathode at F4 at 2 mA. RTMS seems to be effective on unilateral DLPFC at high frequency, with optimal results using deep coil. Medication appeared to have little to no effect in the studies reviewed. However, meta-analysis did not reach significance for any of the techniques studied.

Conclusions: Future research should focus on enlarging the sample sizes for tDCS and TMS, and investigating the effect of comorbidities. Neurofeedback lacks significant study quality. It could still be a viable option, particularly for population reluctant to undergo neuromodulation technics. Combination of tDCS and other therapies may hold significant therapeutic potential.

INTRODUCTION

Attention-deficit with or without hyperactivity disorder (ADHD) is a DSM-V diagnosis characterized by inattentive and/or impulsive/hyperactive symptoms. Given its significant early impact on learnings and educational investments, ADHD is one of the most researched pediatric disorders (Faraone *et al.*, 2021). Identifying this neurodevelopmental irregularity early on can reduce societal costs and prevent social isolation.

However, of the 5.9% of children diagnosed with ADHD, 2.5% of adults will continue to display disabling symptoms (Faraone *et al.*, 2021). There is a lack of research on adults in ADHD literature, and therefore a lack of understanding of their current impact. This subgroup, therefore, requires more thorough research, as to ensure proper care. Adult ADHD presents features distinct than childhood ADHD, in symptomatology (inattentive symptoms seem to be more prominent, Vos & Hartman, 2022), in neurobiology (Cortese *et al.*, 2018) and in environmental consequences (work-life balance, financial issues, social involvements; Courrèges, De Kermadec & Rahioui, 2024). In addition, adult ADHD, is often associated with comorbid disorders (Richter *et al.*, 2007). This phenomenon could theoretically be explained by neuroplastic changes that would have occurred over a lifetime. Undiagnosed patients may maintain deleterious compensatory strategies (*i.e.*, anxious checkings, ruminations) which may negatively affect self-esteem and self-image issues. Reinforced by conditioning processes, it may contribute to potential frequent comorbid disorders such as depressive episodes, addictive behaviors, or sleep disorders.

This makes care for adults with ADHD more complex. The gold-standard pharmaceutical treatment is methylphenidate. This psychostimulant that acts on the dopaminergic regulatory system. It mainly blocks dopamine reuptake in the presynaptic neuron, thereby increasing dopamine concentration forward and therefore enhancing stimulant cognitive effects (Verghese & Abdijadid, 2023). Methylphenidate is thought to facilitate goal-driven behaviors in individuals with ADHD, who often appear to have low dopamine receptor availability in corticolimbic pathways (Mizuno *et al.*, 2023), such as the nucleus accumbens. In children with ADHD, methylphenidate has proven effective (Cortese *et al.*, 2018), helping them to focus, which serves both as a psychoeducational tool and as a learning aid. Nonetheless, methylphenidate, as well as other psychostimulants medication, seems to be less effective and less well-tolerated in adults (Cortese *et al.*, 2018). In addition, there is numerous adverse effects, including gastrointestinal system (*e.g.*, decreased appetite, nausea), cardiovascular system (*e.g.*, tachycardia) or central nervous system (*e.g.*, restlessness, nervousness, insomnia). Additionally, there is a potential risk of substance abuse (Verghese & Abdijadid, 2023).

Adjuvant to medication, behavioral therapies such as cognitive behavioral therapy (CBT) or specific cognitive training have been developed to help manage ADHD. Cognitive behavioral therapy

uses conditioning principles to implement healthy thinking patterns and help patients unlearn maladaptive behaviors. It is well-validated and widely recommended by the French HAS (High Health Authority) for numerous psychiatric affections, including generalized anxiety disorder, panic disorder with or without agoraphobia, social anxiety, phobia, obsessive compulsive disorder, post-traumatic stress disorder (HAS, 2007). Miscellaneous CBT protocols specific to ADHD have been published, targeting executive functions (Solanto, 2011) or the parenting skills of diagnosed children's caregivers (Barkley, 2010). However, a recent consensus in literature has stated that CBT seems only to lead to small improvements when restricted to studies with control groups (Faraone *et al.*, 2021).

Cognitive remediation, on the other hand, focuses on stimulation of cognitive deficits through exercises and strategy implementation. Cognitive training appears to be theoretically highly relevant, since attention is a core cognitive function usually assessed by neuropsychological evaluations on three categories: selective, divided and sustained attention. Nonetheless, methodological limitations often prevent definitive statement on its efficacy as a rehabilitation tool (Tajik-Parvinchi, Wright, & Schachar, 2014). Thus, evidence supporting its validity for the treatment of adults with ADHD care remains scarce and inconclusive.

As a result, scientific literature has explored new perspectives to develop alternative approaches to psychiatric care. New treatments increasingly integrate insights from neurosciences. Neurological abnormalities are frequently studied in the brain anatomy of patients with psychiatric conditions.

Neurodevelopmental disorders, including ADHD, are no exception. Over the last decade, ADHD has been studied through its lens. It is a heterogeneous disorder, to say the least. Nevertheless, certain patterns have emerged across various meta-analyses. For instance, one by Cortese and colleagues (2012) which only comprises fMRI studies, identified abnormal activation of salience network (SN) and hyperactivation of default mode network (DMN) in frontal areas. The SN is thought to highlight important information, thereby directing involuntary, unconscious attention. In contrast, the DMN encompasses brain areas that are active when no cognitive task is being performed, reflecting baseline cognitive activity. In individuals with ADHD, spontaneous activation of the DMN has been observed to occur during periods when it is not required, leading to daydreaming behaviors during a task that require focus. Meanwhile, SN may either be hypoactivated or hyperactivated, making the environment either insufficiently or excessively salient (Gaillac & Vera, 2016). Cortese *et al.*, (2012) found hypoactivation of the frontoparietal network in 97% of their sample in a meta-analysis of functional MRI in adults with ADHD, as well as hyperactivation in visual (41%), dorsal (33%) attention networks, and DMN (26%). Concurrent with these findings, Lubar *et al.*, (1995) had already observed the occurrence of slow wave activity (theta wave) during an on-going cognitive task, which resulted in the development of a neurofeedback protocol, aiming to improve the theta-beta ratio at Cz.

Neurofeedback is a non-pharmacological treatment that has been extensively debated in psychiatric literature. This method combines principles of CBT (including conditioning, positive reinforcements, strategy implementation within a therapist-patient collaboration) with electroencephalogram (EEG) feedback. Electrodes are placed above specific brain areas, and patients are guided in regulating brainwaves activity to reach a predefined threshold (Arns *et al.*, 2009). As stated, validity and efficacy of EEG feedback is still of debate, but it has been deemed effective specifically for ADHD, achieving a level 5 (efficient and specific), according to AAPB and ISNR guidelines. A substantial effect size has been demonstrated in the reduction of inattention symptoms (Arns *et al.*, 2009).

In recent years, neuromodulation technologies have emerged as innovative tools in neuropsychiatric care. Repetitive transcranial magnetic stimulation (rTMS) is a relatively new approach based on electromagnetism laws. The induction of an electric field is generated by the passage of a magnetic one through conductive material (as the scalp). When of high frequency (>1 Hz), this leads to the depolarization of the superficial neuronal layer and stimulation of connected networks (Tikka *et al.*, 2023).

In contrast, transcranial direct current stimulation (tDCS), operates through a different mechanism. In tDCS, an electric current (typically ranging from 1 to 2 mA) is delivered through the scalp, with the objective of modulating the resting state membrane potential (Fregni *et al.*, 2021). It is hypothesized that this will induce a subthreshold shift, resulting in subsequent depolarization or hyperpolarization (Lefaucheur *et al.*, 2017). The polarity of the stimulation determines the direction of the effect, anodal (excitatory) stimulation facilitates, while cathodal (inhibitory) stimulation hinders, preventing future depolarization. Both rTMS and tDCS primarily affect superficial layers of neurons, as they are non-invasive techniques. However, they are both thought to influence distant cortical to subcortical activities, through interconnected neuronal networks (Fregni *et al.*, 2021). As the electric current spreads deeper and its intensity decreases, it modifies the subsequent recruitment of networks and results in biological and clinical effects (Lefaucheur *et al.*, 2017). However, minor variations between studies, as differences in electrode size shape, montage, or exact area, can significantly influence the induced electric current, and, consequently, the clinical outcomes. It is, therefore, essential to develop clear and replicated protocols in order to better understand the impact of tDCS on a neuropsychiatric condition.

At the present time, neither tDCS or rTMS currently have standardized protocols for ADHD. However, major depressive disorder is currently treated with rTMS with the Stanford accelerated protocol – an intensive ten sessions program over five days of theta-burst stimulation. It has reached a promising level of efficacy, garnering interest among professionals worldwide. As for tDCS, protocols for fibromyalgia, depression (medication-resistant) and addiction have reached level B efficacy

(probably efficacy), while chronic neuropathic pain is categorized at level C, in Lefaucheur *et al.*, (2017).

There is a need to clarify the direction for future research, in ADHD. Neurofeedback, tDCS and rTMS represent novel therapeutic interventions that can be used as adjuvant to prescribed medication, psychoeducation or cognitive trainings. A comparison of neurofeedback data with neuromodulation is relevant as to provide a more comprehensive view of their applicability in patient care. TDCS and rTMS data need to be clarified as to know where to lead next.

To address these gaps, a systematic literature review was conducted to evaluate the validity and efficiency of neurofeedback, tDCS and rTMS therapies (multiple-session protocols only), with a population of adults diagnosed with ADHD.

METHOD

Search Strategy

We performed a systematic review following the preferred reporting items for systematic review and meta-analysis (PRISMA) guidelines (see Figure 1). This study was registered at PROSPERO, which is an international database of systemic reviews from the National Institute for Health Research, under the number CRD42024537851. We searched PubMed/MEDLINE, an Ovid merging Embase EBM reviews, and Health and Psychological Instruments (HaPi), Web of Science and Cochrane Library, as well as ScienceDirect, systematically from 1st March of 2024 to 1st June of 2024.

To operationalize the search, we looked for variance of key words pertaining to “ADHD” or “attention deficit” or “attention disorder” or “Attention disorder with hyperactivity” or “Hyperactivity” ; added to “adult” or “grown-up” in a title and abstract-focused search. Depending on the therapy targeted, were included key-words addressing either neurofeedback (or “EEG biofeedback” OR “EEG feedback”) ; tDCS (or “Transcranial Direct Current Stimulation” or “direct current stimulation” or “anodal stimulation” or “cathodal stimulation”) ; and TMS (or “transmagnetic stimulation” or “transcranial magnetic stimulation” or “rTMS” or “iTBS” or “repetitive transmagnetic stimulation” or “Transcranial Magnetic Stimulation”).

Exclusion/inclusion criteria

A series of inclusion/exclusion criteria were applied in accordance with the PICO framework. To evaluate the efficacy and validity of comparative therapies within a meta-analysis, only randomized

controlled trials (RCT) were selected. Two case reports for rTMS were included in the systematic review as well.

Only multiple-sessions protocols were considered. Participants had to be adults (age 18 and above) previously diagnosed as ADHD using standardized methods. Outcomes were evaluated based on relevant measures of inattention, impulsivity, and/or quality of life. Studies evaluated were in English.

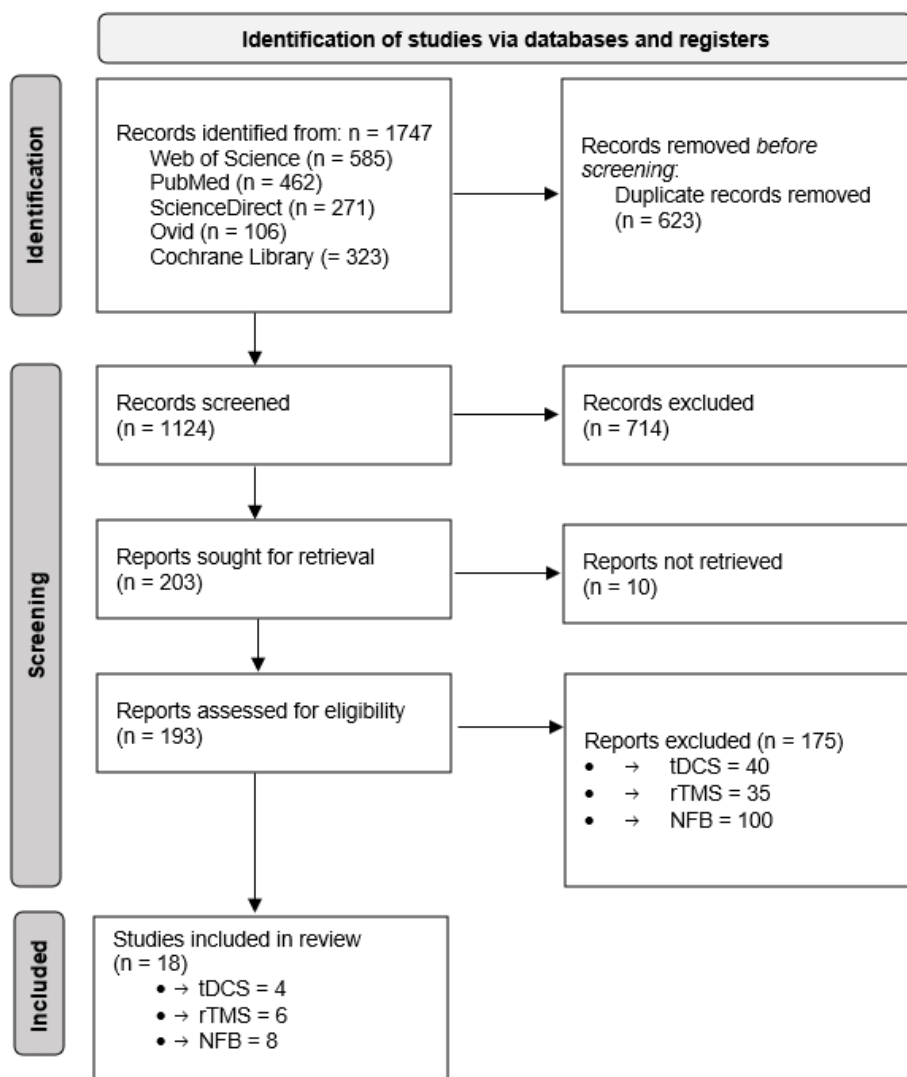
Qualitative studies, studies involving exclusively pediatric populations, using virtual reality as neurofeedback or studies consisting of single-session of neurofeedback, tDCS or rTMS, were strictly excluded.

Data extraction

The initial search identified 1747 articles, of which 623 were duplicates, leaving 1124 papers that were screened for eligibility. Abstracts were reviewed by author M.C. and independently cross-checked by author M.H. to ensure that no studies were missed. Disagreements were resolved through discussion and consensus.

After initial application of inclusion and exclusion criteria, a total of 203 articles for retrieval were selected for full-text review. Upon in-depth investigation, an additional 175 more articles were excluded, due to reasons such as being conference abstracts, methodology articles, unspoken language; or no control group at post-treatment. This left a final sample of 18 studies (Figure 1). Sensitivity analyses were conducted to assess the impact of potential bias on the overall findings. In order to assess the quality of the analyses, Jadad ratings were given for each randomized controlled trial, following Sonuga-Barke *et al.*, (2013) line of work. Jadad scores RCT's randomization quality, blinding quality, and mention of drop outs which are all mandatory to ensure robust findings and potential generalizability.

Figure 1:
Flowchart of literature review following PRISMA guidelines



Funding

No funding was provided for this project.

Ethical statement

Ethical statements were not required for this review

RESULTS

Characteristics of included studies

A total of 18 studies were extracted from the sample, with 4 papers on tDCS protocols, 6 on TMS protocols, and 8 RCTs on EEG feedback.

tDCS

A total of 4 studies were extracted, all of which were single-blind randomized controlled trials (RCTs), with one crossover design (within-subject sham) and one double-blind design. They span from 2017 (Cachoeira *et al.*) to 2023 (Basiri & Hadianfard), and collectively comprised 145 adult participants diagnosed with ADHD. All participants were assessed through standardized self-report scales such as CAARS, ASRS, often supplemented by the Diagnostic Interview for ADHD in Adults (DIVA) based on DSM-V criteria. Neuropsychological assessments, such as the Continuous Performance Test (CPT), were often used. All four studies used a control group, primarily sham groups. However, Basiri & Hadianfard (2023) adopted a comparative approach, evaluating tDCS against dialectic behavioral therapy (DBT), no treatment at all, and a combined tDCS and DBT group (see Table 1).

TDCS sessions were consistent in duration, lasting 20 minutes, ranging from 3 to 10 consecutive sessions total, and an intensity of 1.5 to 2 mA. The dorsolateral prefrontal cortex (DLPFC) was the cortical target for all of them. Barham *et al.*, (2022) and Allenby *et al.*, (2018) both applied anodal stimulation to F3 (left DLPFC) and cathodal stimulation to F4 (right DLPFC) at 2mA. Cachoeira *et al.*, (2017) used the opposite protocol, and Basiri & Hadianfard (2023) applied both anodal and cathodal stimulation at 1.5 mA to F3 and F4 simultaneously.

TDCS randomized controlled trials have all demonstrated positive outcomes with improvements on various measures, either self-rated scales or neuropsychological assessments. This is promising for future research, but the very restricted number of existing studies (four) demands more data. Most studies used comparable parameters, apart from Basiri & Hadianfard (2023) who used bilateral stimulation. All three others used unilateral stimulation, at F3 or F4, at 2 mA. Anodal (excitatory) stimulation at F3 seemed to be more effective, as Cachoeira *et al.*, (2017) only reported improvements in self-rated scales while stimulating F4, but still significant.

Basiri & Hadianfard (2023) featured the largest sample size, 80 participants were assessed and provided valuable insights by comparing therapy approaches. Their findings indicated that concurrent treatments were more effective than isolated treatment, as combined DBT and tDCS showed significant improvement across all variables ($F = 7.96, p = .001$).

This aligns with broader tDCS literature in other conditions (Fregni *et al.*, 2021) which is currently growing steadily. Fregni and colleagues, in 2021, have suggested that the very effect of transcranial electric stimulation, which lowers the threshold for action potentials and thus facilitates latter

depolarizations, could amplify concurrent treatment's effect. Enhancing the cortical excitability with tDCS, while exciting the cortex with TMS or cognitive therapies, is an axis of interest for future therapeutic researches.

A key limitation of existing tDCS studies is follow-up assessments. Allenby *et al.*, (2018) explored follow-up only three days post-treatment, but even after this short length of time, they found that CPT improvements were not sustained. More data are needed to assess the longevity and generalizability of treatment effect.

Medication use varied across studies, with no observed impact on outcomes. Basiri & Hadianfard (2023) did not specify any use of pharmacological drug, Barham *et al.*, (2022) exclusively selected drug-naïve participants, Cachoeira *et al.*, (2017) required their participants to discontinue all medication one month prior to the study, and Allenby *et al.*, (2018) permitted continued use of medication.

Two reported minimal side effects. Allenby *et al.*, (2018) reported “burning, itching and tingling” sensations which seemed to resolve after discontinuing treatment. Cachoeira *et al.*, (2017), similarly reported “itching sensations” but also, documented “one acute mood change” amongst their patients.

Jadad ratings classified all randomized controlled trials in high quality studies, since all of them randomized and blinded their studies with caution for drop outs, sometimes with detailed explanation.

Table 1:
Summary of tDCS extracted RCTs

Authors	N (ADHD)	Current comorbidity allowed	Medication	Study Design	Testing	Protocol	Duration	Control group	Result	Jadad scale	ES (se)
Nooshin Basiri & Habib Hadianfard (2023)	80 (mean age 23; 17 males)	None	Not specified	RCT	ASRS, DERS, Stroop, CPT	F3 F4 (both anodal + cathodal) 1,5 mA	20 mn over 10 sessions, 72 h between sessions (30 days total)	DBT vs no treatment vs TDCS vs Combined	TDCS + DBT enhanced everything	3	1.1093 (0.3664)
Huzeyfe Barham <i>et al.</i> , (2022)	22 (mean age 22; 7 males)	None	Drug-naïve	RCT	ASRS + neuropsychy	anode at F3, cathode at F4, 2mA	20 mn over 5 sessions	Sham	TDCS significant for some neuropsychological assessments (digit span)	4	0.4866 (0.4327)
Carolina Tosetto Cachoeira <i>et al.</i> , (2017)	17 (age from 18 to 45)	None	Stopped one month prior	RCT double blind	ASRS	Anode at F4 (right DLPFC) cathode at F3 2 mA	20 mn/day for 5 days	Sham	TDCS significant on self-report scales	5	1.8857 (0.5838)
Cheyenne Allenby <i>et al.</i> , (2018)	35 (mean age 31.7; 26 males)	None	Ongoing	Crossover	Neuropsychy	Anode at F3, cathode at F4, 2mA	20 mn over three sessions separated by 24h, wash out period, repeat	Within subject sham, randomized & counterbalanced	TDCS significant on CPT false positive errors	5	0.0602 (0.2391)

Nb: RCT: randomized controlled trial. TDCS: transcranial direct current stimulation. DLPFC: dorsolateral prefrontal cortex; DBT: dialectic behavioral therapy.

TMS

Six (6) studies were extracted from the databases, four of them being RCTs (2 double-blinds, one semi-blind, one crossover design), and two being single case reports. These studies span from 2012 (Niederhofer) to 2021 (Bleich-Cohen *et al.*) (see Table 2); and, together, comprised one hundred and fifty-one (151) participants diagnosed with ADHD, using standardized ADHD diagnostic tools (as tDCS). Apart from case reports, all of them presented control groups, either sham, or real stimulation, as in Alyagon *et al.*, (2020).

As for technical parameters, sessions ranged from 5 to 20 times, once a day. Exact duration of each session was not specified, except in Niederhofer (2011) whose sessions lasted 1 hour in his case report. Frequencies were inconsistent, but remained in the high frequency (excitatory) range, from 1 to 18 Hz, at 100 to 120 % of motor threshold. Coils varied as well, using H6, H5, 8 or cool-B65 coils. Only two studies, Bleich-Cohen *et al.*, (2021) and Alyagon *et al.*, (2020), consistently used a H6 deep TMS coil. The cortical target was, overall, the prefrontal cortex, stimulated either unilaterally (left or right hemisphere) or bilaterally, either dorsolateral or ventrolateral (see Table 2). Only Niederhofer (2012) targeted a motor area.

Out of all studies, one reported no improvement at all, on any variable: Paz *et al.*, (2017) used TOVA as a cognitive assessment and CAARS as a symptom scale pre- and post-treatment, and found no significant effects against sham. The authors conclude that bilateral DLPFC stimulation is not effective compared to unilateral stimulation.

The other five reported improvements in at least one variable, especially inattention symptoms and executive functions. For instance, Alyagon *et al.*, (2020) found improved Stroop performance, and Bleich-Cohen *et al.*, (2021) demonstrated sustained effects over two follow-ups.

Deep TMS (dTMS) using H6 or H5 coils can penetrate deeper cortical layers, beyond the superficial 3 cm of standard rTMS. It has been used in psychiatric conditions, *e.g.*, in depression, targeting subgenual cingulate cortex Cg25. It is the coil used in Alyagon *et al.*, (2020) whose results suggest possible efficacy. Two studies (Ustohal *et al.*, 2012; Weaver *et al.*, 2012) used 8 coil configurations. Ustohal *et al.* (2012) reported worsening of emotional dysregulation specifically over stimulation of right DLPFC, and Weaver *et al.* (2012) reported improvements only on a quality-of-life scale (*i.e.*, CGI) and no changes in inattention or impulsivity scores.

RCTs used from 5 to 15 sessions, with a seemingly better outcome with 15 sessions, sustained in two follow-ups in Bleich-Cohen *et al.*, (2021). Unilateral left stimulation seemed to be most indicated, to be evaluated with caution when caring for patients with comorbid depressive symptoms, as demonstrated in Ustohal *et al.* (2012)'s case report.

Table 2:
Summary of rTMS extracted studies

Authors	N (ADHD)	Current comorbidity allowed	Medication	Study Design	Testing	Protocol	Duration	Control group	Result	Jadad scale	ES (se)
Maya Bleich-Cohen <i>et al.</i> , (2021)	75 (age from 18 to 60; 49 males)	Mild depression and anxiety	Stopped 3 days before, SSRI ongoing	Double-blind RCT	CAARS + CGI + neuropsy	dTMS H6 coils, right DLPFC & left DLPFC; 40 trains of 18 Hz pulses 120% M T	15 sessions over 3 weeks, then 2 follow ups	Sham	Correlation of ↑ rDLPFC with CAARS; ↑ FC with some of the DMN	5	-0.4492 (0.2930)
Helmut Niederhofer (2012)	1 female, age 42	None	Ongoing	Single case	Conners	1Hz, 1200 stim above the motoric area with Cool-B65 Coil	5 sessions of 1 h	None	Reduction in hyperactivity symptoms, no reduction in attention symptom	1	NA
Uri Altyagon <i>et al.</i> , (2020)	43 (age from 21 to 46; 30 males)	None	Stopped during & a week before trial	Active, active control, and sham RCT	EEG + CAARS, BAARS, BRIEF A, BDI + neuropsy	H6 coil, target DLPFC and VLPFC	15 sessions single-pulsed over 3 weeks, and follow up at 1 month	AC with real stim elsewhere, patients blinded, operators semi-blinded	rPFC stimulation correlated with a Stroop improvement and CAARS, ratio of low Gamma to Alpha activity correlated with ADHD symptom	4	0.9359 (0.3914)
Libor Ustohal <i>et al.</i> , (2012)	1 (36 years old male)	Depression	AD	study case	D2 and MADRS	1 sham, 1 left, 1 right DLPFC (120% M T) 8-coil	5 sessions of each, 1500 stim per session	None	Improvement of D2 with left DLPFC stim, but worsening + emotional disrupts with right DLPFC stim	1	NA
Yaniv Paz <i>et al.</i> , (2017)	26 (mean age 31; 14 males)	Not mentioned	Stopped 48h prior	Double blind RCT	TOVA CAARS	H5 dTMS over bilateral PFC, 55 trains of pulses at 18Hz at 120% M T	daily for four weeks = 20 sessions	Sham	No improvements on CAARS, no improvements on TOVA	4	-0.1188 (0.434)
Laurel Weaver <i>et al.</i> , (2012)	5 (mean age 19; 2 males)	Anxiety	MTP ongoing, AD stopped 2 weeks prior	Crossover	CGI + ADHD scale + neuropsy	8-coil, 10 Hz, at 100% of M T, 2000 pulses per session	5 days treatment, 5 days stop, 5 days sham	Crossover	No neuropsychological differences but improvements on CGI and on ADHD scale	4	0.341 (0.478)

Nb: DLPFC: dorsolateral prefrontal cortex; VLPFC: ventrolateral prefrontal cortex; M T: motor threshold; FC: functional connectivity; mPFC: medioprefrontal cortex; PCC: posterior cingulate cortex; dTMS : deep transcranial magnetic stimulation; AD : antidepressant

Methylphenidate medication was usually discontinued. On the aforementioned Ustohal's case report, antidepressants were continued. For Weaver *et al.*, (2012), methylphenidate and antidepressants were continued as well, presenting with ADHD and comorbidities such as generalized anxiety disorder or phobia. No interference was reported.

Interestingly, Niederhofer (2012) used a completely different process. He reported the study case of a woman diagnosed with the hyperactive subtype and no comorbidity. They allowed methylphenidate ongoing during treatment, and targeted the right motor area with a cool B65 coil with low-frequency (1 Hz) for five 1 hour-sessions. This uncommon procedure resulted in no effects on inattention scores, but improvements in impulsivity and subsequent lowering of methylphenidate dosage. This highlights the possibility of targeting specific dimensions, such as impulsivity, by stimulating motor regions. This opens avenues for dimensional approaches aligned with RDoC frameworks.

As for side effects, headaches have been primarily reported (Weaver *et al.*, 2012; Paz *et al.*, 2017; Alyagon *et al.*, 2020). Niederhofer (2012) reported no complaints, while Bleich-Cohen *et al.*, (2021) did not specify. Ustohal *et al.*, (2021)'s case report mentioned, with right DLPFC stimulation, "dysphoria, inability to respond emotionally, hypobulia, tension and also impaired attention" (Ustohal *et al.*, 2012).

Jadad ratings also report high-quality studies.

Neurofeedback

The 8 neurofeedback trials spanned from 2010 (Logemann *et al.*) to 2021 (Barth *et al.*; Schönenberg *et al.*) and investigated four main protocols: Thêta/bêta Ratio (TBR), Sensorimotor Rhythm (SMR), Slow Cortical Potential (SCP), and Quantitative-based neurofeedback (QEEG). These studies involved 376 individuals, assessed previously with the same standardized ADHD scales as tDCS and rTMS (see Table 3); this sample excludes Bink *et al.*, (2014) who did not state how many adults were in their study.

Neurofeedback offers four standardized protocols for managing ADHD. The most famous is the theta/beta ratio (TBR) protocol, which was developed by Lubar *et al.*, (1995), and targets a decrease of theta waves (4-7 Hz), and an increase of beta waves (12-20 Hz) in the frontoparietal area. Another well-known protocol is the sensorimotor rhythm, a specific subset of beta waves (12-15 Hz) associated with an alert mental state and calm motor state. Initially designed for epilepsy management, the SMR has been also studied for ADHD. The third protocol is slow cortical potential (SCP) training, which differs from the others by targeting electric potentials rather than brainwaves.

Table 3:
Summary of neurofeedback extracted RCTs

Authors	N (ADHD)	Current comorbidity allowed	Medication	Study Design	Testing	Protocol	Duration	Control group	Result	Jaded scale	ES (SE)
Barth et al (2021)	67 (mean age 32.84; 44 males)	Not mentioned	Ongoing	RCT, open-label	ADHS-SB + German DIVA + neuropsychy	SCP-NF; NIRS-NF	30 sessions	EMG (biofeedback)	Time effect for all groups in inattention, hyperactivity/impulsivity and depression	4	0.0045 (0.26)
Keith et al (2015)	95 (mean age 34; 59 males)	Substance use	No	RCT, open-label	TOVA	SMR + \uparrow β + \downarrow $\alpha\theta\delta$	15 sessions 2 x a day	TAU	QEEG groups improved in commission errors, RT and variability	1	1.02 (0.285)
Cowley, et al (2016)	54 (mean age 36; 25 males)	Not mentioned	Stopped	RCT, open-label	TOVA, ASRS, digit-span	QEEG: SMR or TBR from iAPF	40 sessions over about 3 months, 2 to 5x a week	WLC	Improvement on self-report inattention and hyperactivity but not on TOVA scores	2	0.604 (0.31)
Ryoo et al (2015)	8 (age not specified)	None	No	Open-label	EEG + CPT + CAARS + Brown	SMR + \uparrow β + \downarrow θ	15 sessions, 3 x a week	8 other ADHD students, WLC	CPT reduction of error commission, omission and RT (Only NFB group showed significant in CAARS)	1	0.83 (0.52)
Zilverstand, et al (2017)	7 (mean age 36.3; 6 males)	None	Both	RCT, open-label	ADHD scale + neuropsychy	\uparrow dorsal anterior cingulate cortex	4 sessions of 1h, 1x a week	6 other ADHD participants, WLC	No differences in clinical outcome, better performances on neuropsychologic tests for NFB	3	0.26 (0.55)
Bink et al (2014)	some were 21 to 24 years old, out of 45 adolescents	Depression, anxiety, substance use, conduct, learning and others	Ongoing	RCT, blinded	ADHD rating + D2 + neuropsychy	\uparrow SMR + \downarrow θ or gamma	40 sessions of 30 min tot. 2 to 3 x a week	Some of 26 TAU, matched with experiment	All groups demonstrated improvement no difference between EEG and TAU	4	-0.12 (0.24)
Schönenberg, et al (2021)	118 (mean age 37.95; 64 males)	None	Ongoing	RCT triple blinded	CAARS + BDI + STAI + FPTM (expectation) + neuropsychy	Not specified	15 sham, 15 verum, 1h/week	Within subject design in sham NFB + CBT training	No differences occurred between treatment groups with regard to symptom improvement and amelioration of cognitive deficits during therapy	1	-0.09 (0.97)
Logemann et al (2010)	27 (mean age 20.9; 3 males)	None	No	RCT	CPT + ASRS + STIMP (impulsivity)	QEEG	16 sessions of 22 min 2x/week	Sham	No significant time*group interactions, or trends towards significance, for any of the dependent variables	4	-0.62 (0.48)

Nb::; iAPF: individual alpha peak frequency; WLC: waiting list control; RT: reaction time

Quantitative EEG (QEEG) refers to all three techniques. A prior EEG assessment identifies occurrence abnormalities; then, one would follow the most adequate neurofeedback protocol. This tailored approach aligns with the personalized-medicine principle, reflecting the future direction of care policies.

Out of the 8 that involved a group control with assessment at post treatment, 3 used a waiting list, 1 was a crossover design, 1 sham, 2 were treatment as usual (TAU), and 1 used EMG feedback (biofeedback).

Duration ranged widely, from 4 to 40 sessions in total, lasting from 20 minutes to 1 h, occurring from 1 to 3 times per week. This massive inconsistency complicates comparisons and the ability to draw conclusions.

Outcomes were measured through self-rated scales (as CAARS, *e.g.* Schönberg *et al.*, 2017; Cowley *et al.*, 2016), neuropsychological tests (as TOVA or CPT assessment, *e.g.* Ryoo, 2015; Logemann *et al.*, 2010), and electrophysiological pre-post evaluations.

Three reported positive outcomes: Keith *et al.*, (2015), Cowley *et al.*, (2016) and Ryoo *et al.*, (2015) concluded to an effectiveness of their neurofeedback protocol. All the others reported mixed results to no improvement at all (see Table 3).

Medication was either stopped, ongoing, or both.

Jadad ratings varied. Often, drop outs were not accounted for, and none of the analyzed studies reported a specific randomization process. Schönberg (2017) claimed to be triple-blinded but used open intervention in their procedure (meta-cognitive therapy).

Analysis

Each study was systematically assessed and assigned a Jadad score depending on the quality of their study, following Sonuga-Barke *et al.*, (2013) assessment of ADHD psychological interventions' meta-analysis. A Jadad score ranges from 0 to 5, with a maximum of 2 points for adequate and detailed randomization process, a maximum of 2 points for adequate and detailed blinding process and 1 point for clear assessment of attrition (dropouts). The Jadad scale allows an estimation of the quality of a randomized controlled trial and therefore a comparison of results (a detailed breakdown of Jadad analysis for each study can be supplied).

Each study was systematically assessed to extract an effect size. It is of importance to note that these effect sizes are solely measures of inattention, and never of impulsivity or executive dysfunctions. Measures of inattention were the most common across studies so they were selected to ensure the highest possible degree of consistency.

Across studies, measures of inattention varied, so assessment selection was as follows: if available, Continuous Performance Test was the most commonly used neuropsychological testing, and omission errors or true positive errors were extracted at post-treatment assessment, comparing active group vs sham group, were extracted. If not available, CAARS was the most standardized self-rated scale across studies and the index of inattention symptoms was extracted. If CAARS was not available, ASRS measure of inattention was used, or the equivalent in local language (*e.g.*: ADHS-SB in German). If neither CPT or CAARS were available, then the most validated neuropsychological assessment was extracted, as for Bink *et al.*, (2014) who provided D2-R data, or Keith *et al.*, (2015) who provided TOVA scores (a detailed breakdown of each measure can be supplied). For each effect size, the mean score and standard deviation or standard error measure was compared between active and sham and standardized mean difference was computed through R (R studio, 2023.06.1). Random-effect model was used. Only one study across the three groups did not report either sufficient neuropsychological data or self-rated scores, but global improvement index (CGI; Weaver *et al.*, 2012) and even if included, was analysed with caution.

The meta-analysis of RCTs for neurofeedback yielded a non-significant small positive effect of 0.28, as the CI of the standard mean difference contains zero [-0.19; 0.74] with a random effect model. The heterogeneity between studies is significant and high (>50 %). The prediction interval mirrors the uncertainty for future studies and what researchers might expect. G were calculated rather than Cohen's d accordingly with the very small number in some samples.

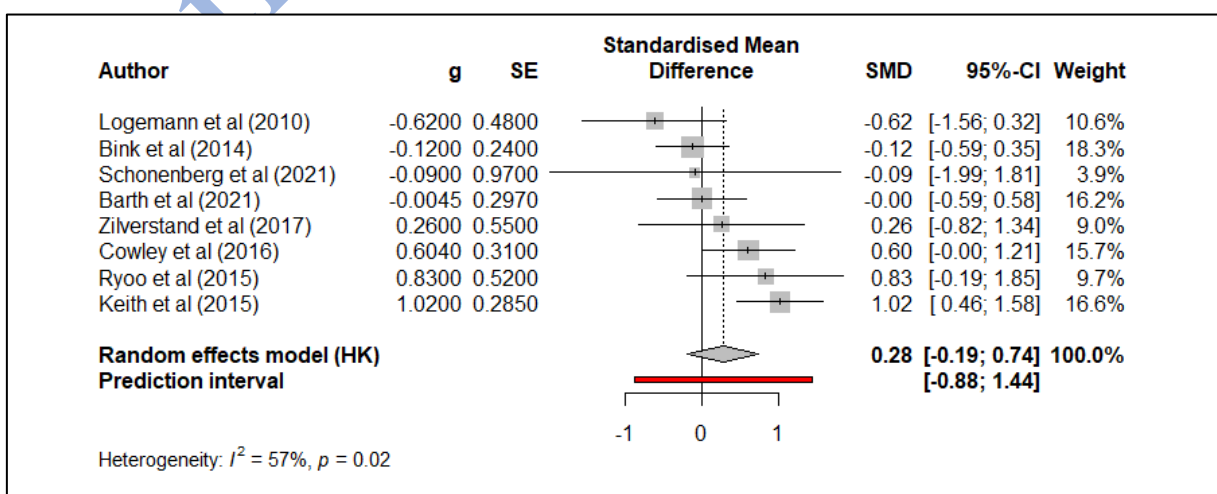


Figure 2:
Diamond graph for neurofeedback

Four TDCS studies included in meta-analysis statistics yielded a random effect with an SMD of 0.79, indicating a moderate positive effect, but not significant ([-0.43; 2.01]). The prediction interval is also not significant ([-2.40; 3.98]) and since no conclusions can be drawn from the pooled SMD, there is a need for caution in generalizing results. However, as individual studies, Basiri & Hadianfard (2023) as Cachoeira *et al.*, (2017) effect sizes do not include 0, suggesting the intervention used might have been effective in their specific settings. Nonetheless, the very high heterogeneity index (74%) calls for great caution and further analysis.

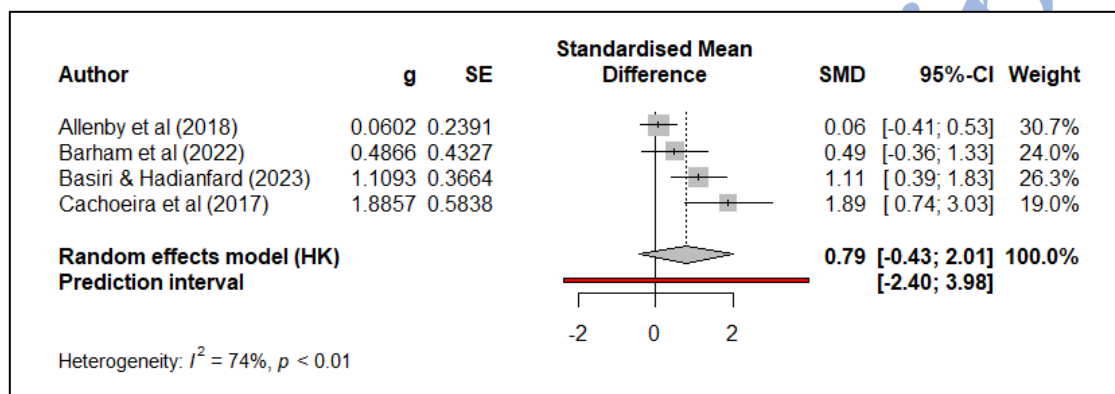


Figure 3:
Diamond graph for tDCS

As for rTMS studies, out of 6 final studies reviewed, 2 were excluded from the meta-analysis due to being single case reports. This left four studies for analysis, which yielded an overall small effect size (SMD = 0.15), not significant ([-0.84; 1.13]). The heterogeneity is high (65%) and the wide prediction interval ([-2.45; 2.74]) suggests high uncertainty for studies going forward, ranging from strongly negative to strongly positive effects.

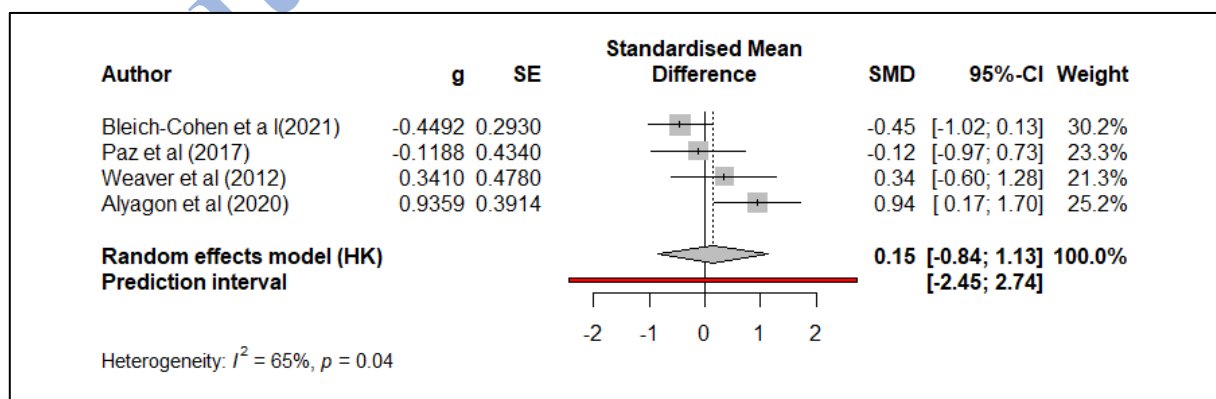


Figure 4:
Diamond graph for rTMS

Subgroup analyses were required for each meta-analysis, to investigate high heterogeneity within studies. However, the small sample for each therapy limited the subsequent subgrouping. Despite this fact, exploratorily, studies in each category were grouped by quality score (Jadad rating, ≥ 3 for high quality studies since 3 = fair), by measures of attention used (self-rated vs neuropsychological assessment) by protocol within the category (*e.g.*: SMR only vs QEEG for neurofeedback studies) and by use of medication (*e.g.*: ongoing, discontinued). Common tau was estimated to investigate between-study as well as within-study residual heterogeneity. Only significant data is reported in Table 4, non-significant analyses can be supplied.

Table 4:
Assessment of heterogeneity

Neurofeedback: quality of the study					
	SMD	95%CI	Q	I ²	p
High	-0.11	[-0.51;0.29]	1.71	0.00%	
Low	0.79	[0.32;1.27]	1.84	0.00%	
Between-studies			21.46		<0.0001
Within-studies			3.55		0.74
rTMS: Protocol used					
	SMD	95%CI	Q	I ²	p
dTMS	-0.34	[-2.29;1.60]	0.4	0.00%	
rTMS	0.69	[-3.01;4.40]	0.93	0.00%	
Between-studies			10.02		0.0015
Within-studies			1.33		0.5155

Meta-regressions were used to assess the predictive power of this heterogeneity analysis. The quality of studies of neurofeedback was explored as a moderator of efficiency, and yielded an effect of low quality (estimate = 0.903, $p = 0.0035$) vs high quality (estimate = -0.109 at $p=0.425$), with a residual heterogeneity of 0% (I^2) and a strong trend of moderator effect ($F = 21.6$, $p = 0.003$).

Protocols for rTMS were assessed as well, differentiating between deep TMS coil and standard TMS coil (as 8-coil). The residual heterogeneity also reached 0%, but although it shows a strong trend ($F = 10.89$, $p=0.05$) the moderator does not reach significance with usual TMS coil (estimate = 1.042; $p = 0.08$) estimated to be more efficient than deep TMS coil (estimate = - 0.345; $p = 0.22$); meaning that even if potentially influencing results, the protocol used cannot be the only moderator.

Publication bias was assessed through Eggers' tests. For tDCS, the regression model was not significant ($t = 2.513$; $p = 0.128$) meaning that the model did not find effects of bias in the analyzed studies. For rTMS, the same conclusion was reached ($t = 1.021$; $p = 0.415$). For neurofeedback, the regression was, as well, not significant ($t = -0.128$; $p = 0.902$). Therefore, funnel plots were not extracted to visualize asymmetry.

Finally, a frequentist network meta-analysis was conducted with a random effect model, in order to compare intervention techniques, with treatment as usual “tau” as reference. Results are reported in Table 5.

Table 5:
Network meta-analysis results

treatment	SMR	95%CI	z	p
EMG	0.4213	[-0.8727; 1.7153]	0.64	0.5234
NFB	0.4258	[-0.3046; 1.1562]	1.14	0.2532
real stim	-0.3515	[-2.1382; 1.4351]	-0.39	0.6998
rTMS	0.5844	[-0.7578; 1.9266]	0.85	0.3935
sham	0.7117	[-0.4429; 1.8662]	1.21	0.227
tau
tDCS	1.2417	[0.0517; 2.4318]	2.05	0.0409*
wlc	-0.0701	[-1.0602; 0.9200]	-0.14	0.8896

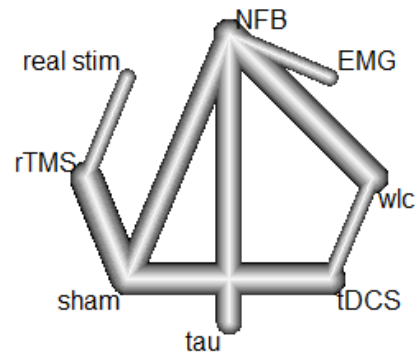


Figure 5:
Graph of network meta-analysis results

Tau² was different than 0 and I² = 57% [13.3%;78,8%], again highlighting heterogeneity in treatment effects. Q within designs was significant within designs (Q = 20.70; p=0.008) but not between designs (Q=0.29; p=0.58).

To check for consistency across our network, we split the results into direct and indirect evidence, to control for inconsistency in the estimates of individual comparisons between techniques in our fitted model. Figure 6 is a forest plot of the subsequent analysis, excluding rTMS due to insufficient data.

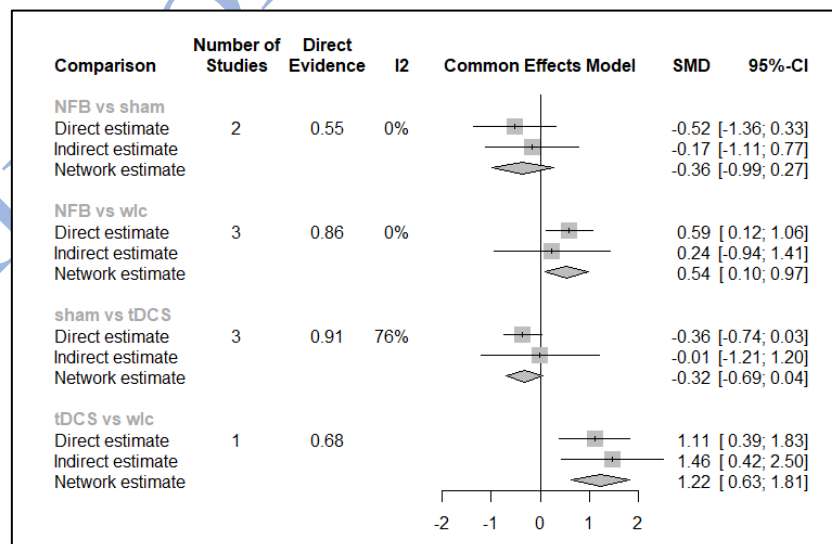


Figure 6
Forest plot of split estimates in direct and indirect evidence

DISCUSSION

This present systematic review sought to investigate the efficacy and validity of neurofeedback, transcranial direct current stimulation (tDCS) and repetitive transcranial magnetic stimulation (rTMS) treatments for ADHD. The objective was to evaluate the comparative therapeutic potential interest and to determine on what grounds future research should be based on. Only multiple-session protocols were included, ensuring a comparison of therapeutic outcomes in adults with a pre-existing diagnosis of ADHD. Only studies that included a control group were analyzed, as to isolate the specific therapeutic effect of the treatment of interest. Outcomes included assessed quality of life, as well as inattention and impulsivity scores. Neurofeedback, tDCS and TMS all employed analogous procedures, evaluating pre- and post-treatment with standardized measures, either self-rated scales or neuropsychological assessments, or both.

Effect sizes for meta-analysis were selectively sought in each paper, solely evaluating the efficiency of attention at post-treatment compared to a control group. Here is a reminder for researchers to report essential data such as mean scores and standard deviations, either within the article or in a supplementary material. This smooths the international dialogue that is experimental research, thereby allowing robust data analysis.

Neurofeedback

The present findings contribute to the current discussion about neurofeedback. Its use has been of debate for some time (Arns *et al.*, 2009; Ros *et al.*, 2020). Methodological challenges in neurofeedback studies have been previously identified, as Ros *et al.*, published in 2020 guidelines for well-conducted randomized controlled trials in this specific therapeutic area. The necessity of control groups and thorough methods section is critical.

In the process of this literature review, a recurring pattern of methodological issues were found in neurofeedback studies, casting doubts on the potential reliability of the outcomes and impeding the evolution of the field.

With regard to the meta-analysis, neurofeedback as a therapy yielded a non-significant effect, with a standardized mean difference largely including 0. Furthermore, the heterogeneity and meta-regression analysis showed a significant effect of the quality of study as measured by the Jadad rating. The findings indicate a weak trend in which outcomes from low-quality studies exhibited a tendency to be more positive.

It is of note, however, that the utilization of sham protocols as control groups need further discussions. It is noteworthy that neurofeedback can be considered as an operant conditioning therapy, and, as of yet, the blinding in sham conditions may not be effective (Pigott *et al.*, 2021). Just as therapeutic care in CBT or psychoanalysis cannot be assessed using blind and sham-controlled trials, neurofeedback blinding protocols may lead to biased results and to biased conclusions and skew results to placebo effect (Pigott *et al.*, 2021). This is merely a comment, since studies could have reached a “high” level of quality with thorough randomization process and mention of drop outs. Nevertheless, the data presented here does point toward a placebo effect of neurofeedback.

On another note, Veilhati *et al.*, (2021) conducted a retrospective data analysis from Cowley *et al.*, (2016). They found a significant effect among a subgroup of participants identified as “learners” within the active neurofeedback group. This finding underscores the importance of pre-screening participants, to distinguish, prior to any protocol, those who will respond positively as “learners” versus those who will not as much as “non-learners”. By identifying these subgroups early on, researchers and clinicians would optimize treatment outcomes, offering QEEG-based neurofeedback protocols only to patients likely to benefit from them.

The identification of prior indications may be expanded to other therapeutic methods. Potential learners could be guided through their adequate type of intervention as to ensure efficient and precise care, and prevent therapeutic wanderings. This hypothesis requires stratification of patients prior and to and following protocols.

TDCS

Transcranial direct current stimulation (tDCS) has shown promising results for adults with ADHD, when applied at 1.5 to 2 mA, with the anode positioned on F3 (left DLPFC), and the cathode on F4, for a duration of 20 minutes across consecutive sessions. Medication status does not seem to significantly influence the outcomes. Cognitive functions appear to improve on neuropsychologic testing, but follow-up studies are needed to evaluate the sustainability of these effects. Future research should focus on enlarging sample sizes, and investigating the impact of comorbidities and symptoms clustering. Interestingly, repeated tDCS sessions seem to improve both impulsivity and inattention, suggesting a potential treatment for hyperactive-type ADHD. This needs to be thoroughly assessed through meta-analyses as well, since the current study only assessed inattention.

One pitfall of tDCS protocols compared to rTMS and neurofeedback-QEEG, is the lack of personalization in current application, which is standardized across all patients rather than tailored to specific neuroanatomy. Moreover, the electric current distribution across the scalp is diffuse, which complicates further any customization.

One major advantage of tDCS is its possible combination with other therapeutic protocols. Its putative effect of facilitating future depolarizations (in the case of excitatory stimulation) may enhance the efficacy of concurrent non-pharmaceutical interventions. For instance, Basiri & Hadianfard (2023) demonstrated a large improvement across all variables in a group receiving tDCS and DBT (dialectic behavioral therapy). Consequently, tDCS warrants further investigation as an adjuvant therapy, alongside CBT, cognitive training, or even neurofeedback or TMS. Comprehensive evaluation is essential in future research, as Lefaucheur *et al.*, (2017) has mentioned heterogeneous data across other disorders. For example, stroke patients did not improve after robot-assisted training in motor rehabilitation, and a ceiling effect could arise from the consecutive use of tDCS and antidepressant medication.

Cognitive enhancement following tDCS treatment has been investigated in healthy subjects (Lefaucheur *et al.*, 2017). Although attention was not specifically evaluated, general cognitive improvement was observed. Combined with its potential antidepressant effects, tDCS may be of interest in comorbid ADHD. This hypothesis has not yet been investigated yet and requires empirical support. Given the high percentage of comorbidities in this specific disorder (Courrèges, De Kermadec *et al.*, 2024), studying ADHD alongside its comorbidities is a compelling area of research. Lefaucheur *et al.*, (2017) highlighted Segrave *et al.*, 's (2014) study, which demonstrated “that the combination of cognitive control training and tDCS has an augmenting effect on the improvement of depression”. Another common ADHD comorbidity is substance abuse and addiction, which has received a level B recommendation for treatment by tDCS, due to its potential efficacy in reducing cravings and enhancing quality of life (Lefaucheur *et al.*, 2017).

Some studies have also investigated the stimulation of the cerebellar cortex rather than the prefrontal cortex, with tDCS in other neuropsychiatric affections. For instance, case reports in schizophrenia (Laidi *et al.*, 2020) have shown an improvement in cognitive functions after five days of stimulation above the cerebellar area. The impact of the cerebellum in neurodevelopmental disorders has recently gained attention, particularly in autism (Wang *et al.*, 2014). Its involvement in emotional and cognitive regulation could potentially mean that it may influence neurodevelopmental diaschisis and therefore, in the establishment of neural networks over time. The cerebellum can be conceptualized as a hub, offering preferential pathways for interventions, through cerebello-thalamo-cortical loops. This hypothesis warrants further investigation in translational research, where monitoring the cerebellum in mice could help to establish an appropriate protocol for human treatment.

TDCS is recognized as a safe procedure, with the main reported side effect being local skin itching or burns, which resolves after the intervention. These issues can be mitigated by a proper use of gel, cream, and appropriately large wet electrodes, as outlined in the guidelines by Woods *et al.*, (2016).

RTMS

Repetitive transcranial magnetic stimulation seems to be effective when applied to the unilateral DLPFC, at high frequencies of 100 to 120% of motor threshold, using dTMS (H6 or H5 coils) or rTMS (8-coil). Whether stimulation is more effective on the left or right DLPFC remains unclear, and may depend upon comorbidities (Ustohal *et al.*, 2012). Bilateral stimulation, on the other hand, doesn't seem to be effective (Paz *et al.*, 2017). Notably, improvements seem to be sustained at follow-up, which is promising indicator for future patient care. Medication does not seem to influence clinical outcomes.

RTMS offers sustained measurable improvements, with minimal to no side effects. It is evidence-based medicine and could be used alongside other indications for treatment-resistant patients.

One pitfall of rTMS is the high cost of equipment. However, the increasing establishment of neuromodulation centers underscores the growing possibilities of an accessible rTMS device. Future research may evaluate the cost-effectiveness of rTMS. For instance, The SAINT protocol (Stanford Accelerated Intelligent Neuromodulation Therapy; Cole *et al.*, 2022) for treatment-resistant depression is a promising area of study in psychiatry.

Like tDCS, rTMS has been studied in a variety of neuropsychiatric disorders, and has shown encouraging evidence of efficacy. Major depressive disorders have received a recommendation of Level A (proof of efficacy) in accordance with the U.S. FDA approval. Substance abuse has received Level B evidence (probable efficacy). As tDCS, rTMS has been investigated as an adjunct to non-pharmacological therapies. Lefaucheur *et al.*, (2020) report one study from Osuch *et al.*, (2009) showing greater improvement for rTMS combined to cognitive processing therapy for post-traumatic stress disorder, which benefits were sustained at 6-month follow-up.

Further research should explore the potential of low frequency rTMS rather than HF, since it may be more compatible with innate anatomical development (Dufor, Lohor & Sherrard, 2023).

Another point of interest is the targeting parameter. The major advantage of rTMS, over tDCS and neurofeedback, is its high precision in identifying the exact neuroanatomical target to achieve the best possible results. It can focus on a precise structural point on the superficial layer of the cortex, that will stimulate an entire network looping in deep brain areas. In contrast, neurofeedback can only display superficial pyramidal neurons and relies on participants' participation, while tDCS applies a diffuse current that, although effective, cannot be customized to individual neuroanatomy, or rather poorly. RTMS benefits from neuro-navigation, which uses prior MRI to pinpoint the exact location for stimulation, thereby maximizing clinical efficacy.

This advantage should be fully exploited to investigate whether rTMS treatment response in adults with ADHD depends on anatomical characteristics, such as connectivity within salience or default mode networks.

Even if included in the review, single case reports (Ustohal *et al.*, 2012; Niederhofer, 2012) cannot be considered as representative as RCTs and should be taken into account distinctly. In a similar way, only one RCT used an 8-coil rTMS (Weaver *et al.*, 2012) and with a very limited number of participants ($n=5$); therefore, restricting comparison with dTMS and their potential respective efficiency.

Meta-analysis was scarce since only three were actual RCT, and one of them did not report sufficient measure for inattention (Weaver *et al.*, 2012). For effect size, only an index of self-rated global improvement was available. This concludes to a high level of uncertainty for future studies, as outlined by the very wide range of interval.

Both rTMS and tDCS are non-invasive, non-convulsive neuromodulation therapies with little to no side effects. Both are supported by encouraging data, but the limited number of available RCTs prevents from drawing definitive conclusions. Additional studies are imperatively needed to strengthen the evidence base, especially as the heterogeneity assessments all reached a very high percentage (>50%). This means that a moderator that has not been assessed here may be influencing outcomes. The post-hoc analyses did not pin the correct moderator in the use of medication, differences in protocols (*e.g.*: F3 or F4), differences in measures (*e.g.*: CAARS or CPT) or study quality. The small number for each therapy hereby limits the statistical power of the analysis.

Both also benefit from shorter length of treatment completion. While neurofeedback often requires up to 40 sessions to complete a protocol, rTMS and tDCS may produce results in as few as 5 sessions. Nevertheless, neurofeedback has shown positive outcomes as well, and may be a viable option for patients unable or unwilling to undergo neuromodulation techniques.

A limitation to the generalizability of the conclusions here relates to comorbidities and their non-inclusion. As mentioned in the Introduction section, ADHD is a highly comorbid disorder, with an increasing number of pathologies with aging. These results could be biased by the inclusion of patients diagnosed only with ADHD, as reported in the case report of Ustohal *et al.*, (2012) with an adverse effect of rTMS in a patient with a comorbid mood disorder.

More studies are undoubtedly needed to improve the current state of knowledge. While the available data is promising, it remains insufficient to draw statistically robust conclusions.

Due to the very small number of studies for each device but as well within study, all additional analyses are biased and have been conducted exploratorily. It demands more data in order to draw conclusions and every result of the present meta-regression and subgroup analyses are to be considered with caution. For instance, even if yielding significance in subgroup analyses, rTMS *versus* dTMS in the present research depicts one study of rTMS (n=5) compared to mixed results of two dTMS RCTs (n=118 for H6). Homogeneity is imperative for strong statistical analyses. Translational research might help smooth clinical trials with human participants, back-translating to look for most adequate protocol for tDCS or rTMS.

The meta-analyses of this review has highlighted some discrepancies between study qualities, specifically profuse for neurofeedback. The current data are not sufficient to draw any conclusion on specific efficiency versus placebo for each of these techniques, since none reached a SMD that did not include zero.

Interestingly, medication use did not appear to have a significant effect on any of the treatment method used in subgroup regression. In tDCS studies, the apparent heterogeneity was not explained by any of the subgroups that were explored (use of medication, type of protocol, Jadad rating and measure of inattention).

However, the network meta-analysis found solid consistency when the data were analyzed as a network, with consistency between direct and indirect evidence. TDCS shows a tendency towards efficiency against wait list control, sham or treatment as usual but not always reaching significance. RTMS might slightly be more effective than tDCS according to indirect measures (nma = -0.6574) but is not significant.

Neurofeedback shows a small to moderate effect toward efficiency against wait list control, sham or treatment as usual, but similarly, not always reaching significance. Indirect evidence suggests that neurofeedback might slightly be more effective than tDCS (nma = -0.8159) but is non-significant. These findings are not consistent with the meta-analysis of neurofeedback's studies, so their relevance is doubtful.

The very little number of studies included limits the statistical analysis ran here and needs to be replicated with larger samples. Nonetheless, placebo effect seems to be present in all three techniques.

This review has several limitations. First, it relies on published data; however, publication bias in scientific literature often favor the publication of significant findings, potentially excluding trials with contradictory or null results. Even though it was specifically tested for using Eggers' test, it does not exclude any risk of bias. It restricts the comprehensiveness of the present analysis and promotes uncertainty.

Second, this review is limited to English-language databases. Additional databases in other languages may comprise more data that established here. This prevents a more global and comprehensive comparison.

Another significant limitation is the exclusion of recent technological developments, which were not taken into account in this comparative analysis. Variations in designs of electrodes shapes, sizes – such as the use of 256-channel versus 19-channel electrodes headset, and advances like the use of intermittent theta-burst stimulation (iTBS), represent critical differences not factored in here. Future expert reviews zooming in on one single tool should address these technological differences in detail.

Other neuroscientific tools and perspectives were not included in this review. While this study focused on two neuromodulation tools and neurofeedback, other modalities, such as vagus nerve stimulation, or other deep brain stimulation, may also hold therapeutic potential and warrant exploration.

CONCLUSION

This meta-analysis and systematic review of literature highlights the comparative efficacy of neurofeedback, transcranial direct current stimulation and repetitive transcranial magnetic stimulation, exclusively on adults diagnosed beforehand as ADHD, treated with multiple-sessions protocols. We provide an overview of latest evidence, for each tool. We also assess the methodological value of each study. Even if some results are promising, the restricted number of data (of qualitative comparable RCT as well as number of participants within a RCT) restricts conclusions. Homogeneity is imperative for strong statistical analyses. As of the present meta-analysis, all category investigated yielded non-significant SMD and very large prediction interval, tDCS with the highest SMD. As for the review of literature, some very interesting data are extracted. The potential of combining neuromodulation tools with concurrent non-pharmacological therapies is discussed, and stratification of “learners” beforehand in order to better guide patients through their therapeutic journey is mentioned. Some recommendations for researchers interested in assessing one of these devices is available, specifically for the care of ADHD.

Disclaimer

ChatGPT and DeepL write was used for proofreading English grammar mistakes, since none of the authors are native English-speaker. It was their sole use.

REFERENCES

- Allenby, C., Falcone, M., Bernardo, L., Wileyto, E. P., Rostain, A., Ramsay, J. R., Lerman, C., & Loughhead, J. (2018). Transcranial direct current brain stimulation decreases impulsivity in ADHD. *Brain stimulation, 11*(5), 974–981. <https://doi.org/10.1016/j.brs.2018.04.016>
- Alyagon, U., Shahar, H., Hadar, A., Barnea-Ygael, N., Lazarovits, A., Shalev, H., & Zangen, A. (2020). Alleviation of ADHD symptoms by non-invasive right prefrontal stimulation is correlated with EEG activity. *NeuroImage. Clinical, 26*, 102206. <https://doi.org/10.1016/j.nicl.2020.102206>
- Arns, M., de Ridder, S., Strehl, U., Breteler, M., & Coenen, A. (2009). Efficacy of neurofeedback treatment in ADHD: the effects on inattention, impulsivity and hyperactivity: a meta-analysis. *Clinical EEG and neuroscience, 40*(3), 180–189. <https://doi.org/10.1177/155005940904000311>
- Arns, M., Drinkenburg, W., & Leon Kenemans, J. (2012). The effects of QEEG-informed neurofeedback in ADHD: an open-label pilot study. *Applied psychophysiology and biofeedback, 37*(3), 171–180. <https://doi.org/10.1007/s10484-012-9191-4>
- Arns, M., Feddema, I., & Kenemans, J. L. (2014). Differential effects of theta/beta and SMR neurofeedback in ADHD on sleep onset latency. *Frontiers in human neuroscience, 8*, 1019. <https://doi.org/10.3389/fnhum.2014.01019>
- Barham, H., Büyükgök, D., Aksu, S., Soyata, A. Z., Bulut, G., Eskicioğlu, G., & Baral Kulaksızoğlu, I. (2022). Evidence for modulation of planning and working memory capacities by transcranial direct current stimulation in a sample of adults with attention deficit hyperactivity disorder. *Neuroscience letters, 790*, 136883. <https://doi.org/10.1016/j.neulet.2022.136883>
- Barth, B., Mayer-Carius, K., Strehl, U., Wyckoff, S. N., Haeussinger, F. B., Fallgatter, A. J., & Ehlis, A. C. (2021). A randomized-controlled neurofeedback trial in adult attention-deficit/hyperactivity disorder. *Scientific reports, 11*(1), 16873. <https://doi.org/10.1038/s41598-021-95928-1>
- Basiri, N., & Hadianfard, H. (2023). Adult ADHD Treatment Based on Combination of Dialectical Behavior Therapy (DBT) and Transcranial Direct Current Stimulation (tDCS) as Measured by Subjective and Objective Scales. *Journal of attention disorders, 27*(1), 57–66. <https://doi.org/10.1177/10870547221118527>

- Biederman, J., et al. (2012). Longitudinal course of deficient emotional self-regulation CBCL profile in youth with ADHD: prospective controlled study. *Neuropsychiatric Disease and Treatment* 8: 267-276.
- Bink, M., van Nieuwenhuizen, C., Popma, A., Bongers, I. L., & van Boxtel, G. J. (2014). Neurocognitive effects of neurofeedback in adolescents with ADHD: a randomized controlled trial. *The Journal of clinical psychiatry*, 75(5), 535–542.
<https://doi.org/10.4088/JCP.13m08590>
- Bleich-Cohen, M., Gurevitch, G., Carmi, N., Medvedovsky, M., Bregman, N., Nevler, N., Elman, K., Ginou, A., Zangen, A., & Ash, E. L. (2021). A functional magnetic resonance imaging investigation of prefrontal cortex deep transcranial magnetic stimulation efficacy in adults with attention deficit/hyperactive disorder: A double blind, randomized clinical trial. *NeuroImage. Clinical*, 30, 102670. <https://doi.org/10.1016/j.nicl.2021.102670>
- Bunford, N., Evans, S., & Wymbs, F. (2015). ADHD and Emotion Dysregulation Among Children and Adolescents. *Clinical Child and Family Psychology Review*, 18(3), 185-217.
- Cachoeira, C. T., Leffa, D. T., Mittelstadt, S. D., Mendes, L. S. T., Brunoni, A. R., Pinto, J. V., Blazius, V., Machado, V., Bau, C. H. D., Rohde, L. A., Grevet, E. H., & Schestatsky, P. (2017). Positive effects of transcranial direct current stimulation in adult patients with attention-deficit/hyperactivity disorder - A pilot randomized controlled study. *Psychiatry research*, 247, 28–32. <https://doi.org/10.1016/j.psychres.2016.11.009>
- Choi, E., & Lee, W. (2015). Comparative Effects of Emotion Management Training and Social Skills Training in Korean Children With ADHD. *Journal of Attention Disorders*, 19(2), 138-146.
- Cole, E. J., Phillips, A. L., Bentzley, B. S., Stimpson, K. H., Nejad, R., Barmak, F., Veerapal, C., Khan, N., Cherian, K., Felber, E., Brown, R., Choi, E., King, S., Pankow, H., Bishop, J. H., Azeez, A., Coetzee, J., Rapier, R., Odenwald, N., Carreon, D., ... Williams, N. R. (2022). Stanford Neuromodulation Therapy (SNT): A Double-Blind Randomized Controlled Trial. *The American journal of psychiatry*, 179(2), 132–141.
<https://doi.org/10.1176/appi.ajp.2021.20101429>
- Cortese, S., Adamo, N., Del Giovane, C., Mohr-Jensen, C., Hayes, A. J., Carucci, S., Atkinson, L. Z., Tessari, L., Banaschewski, T., Coghill, D., Hollis, C., Simonoff, E., Zuddas, A., Barbui, C., Purgato, M., Steinhausen, H. C., Shokraneh, F., Xia, J., & Cipriani, A. (2018). Comparative efficacy and tolerability of medications for attention-deficit hyperactivity disorder in children, adolescents, and adults: a systematic review and network meta-analysis. *The lancet. Psychiatry*, 5(9), 727–738. [https://doi.org/10.1016/S2215-0366\(18\)30269-4](https://doi.org/10.1016/S2215-0366(18)30269-4)
- Cortese, S., Kelly, C., Chabernaud, C., Proal, E., Di Martino, A., Milham, M. P., & Castellanos, F. X. (2012). Toward Systems Neuroscience of ADHD: A Meta-Analysis of 55

fMRI Studies. *The American Journal of Psychiatry*, 169(10), 1038–1055.

<https://doi.org/10.1176/appi.ajp.2012.11101521>

- Courrèges, M., De Kermadec, J., & Rahioui, H. (2024). Aging ADHD: Case series of patients reaching 45+ with a recent diagnosis of ADHD. In *Annales Médico-psychologiques, revue psychiatrique*. Elsevier Masson.
- Cowley, B., Holmström, É., Juurmaa, K., Kovarskis, L., & Krause, C. M. (2016). Computer Enabled Neuroplasticity Treatment: A Clinical Trial of a Novel Design for Neurofeedback Therapy in Adult ADHD. *Frontiers in human neuroscience*, 10, 205.
<https://doi.org/10.3389/fnhum.2016.00205>
- Dufor, T., Lohof, A. M., & Sherrard, R. M. (2023). Magnetic Stimulation as a Therapeutic Approach for Brain Modulation and Repair: Underlying Molecular and Cellular Mechanisms. *International journal of molecular sciences*, 24(22), 16456.
<https://doi.org/10.3390/ijms242216456>
- Haute Autorité de Santé (2007) *Affections psychiatriques de longue durée. Troubles anxieux graves*. https://www.has-sante.fr/upload/docs/application/pdf/guide_medecin_troubles_anxieux.pdf
- Faraone SV, et al. (2021). *The World Federation of ADHD International Consensus Statement: 208 Evidence-based Conclusions about the Disorder*, *Neuroscience and Biobehavioral Reviews* doi: <https://doi.org/10.1016/j.neubiorev.2021.01.022>
- Fotuhi, M., Khorrami, N. D., & Raji, C. A. (2023). Benefits of a 12-Week Non-Drug "Brain Fitness Program" for Patients with Attention-Deficit/Hyperactive Disorder, Post-Concussion Syndrome, or Memory Loss. *Journal of Alzheimer's disease reports*, 7(1), 675–697.
<https://doi.org/10.3233/ADR-220091>
- Fregni, F., El-Hagrassy, M. M., Pacheco-Barrios, K., Carvalho, S., Leite, J., Simis, M., Brunelin, J., Nakamura-Palacios, E. M., Marangolo, P., Venkatasubramanian, G., San-Juan, D., Caumo, W., Bikson, M., Brunoni, A. R., & Neuromodulation Center Working Group (2021). Evidence-Based Guidelines and Secondary Meta-Analysis for the Use of Transcranial Direct Current Stimulation in Neurological and Psychiatric Disorders. *The international journal of neuropsychopharmacology*, 24(4), 256–313. <https://doi.org/10.1093/ijnp/pyaa051>
- Gaillac, V., & Vera, L. (2016). *Prendre en charge les adultes souffrant de TDAH (Les Ateliers du praticien)*. Dunod.
- Groeneveld, K. M., Mennenga, A. M., Heidelberg, R. C., Martin, R. E., Tittle, R. K., Meeuwse, K. D., Walker, L. A., & White, E. K. (2019). Z-Score Neurofeedback and Heart Rate Variability Training for Adults and Children with Symptoms of Attention-Deficit/Hyperactivity Disorder: A Retrospective Study. *Applied psychophysiology and biofeedback*, 44(4), 291–308. <https://doi.org/10.1007/s10484-019-09439-x>

- Keith, J. R., Rapgay, L., Theodore, D., Schwartz, J. M., & Ross, J. L. (2015). An assessment of an automated EEG biofeedback system for attention deficits in a substance use disorders residential treatment setting. *Psychology of addictive behaviors: journal of the Society of Psychologists in Addictive Behaviors*, 29(1), 17–25. <https://doi.org/10.1037/adb0000016>
- Klefsjö, U., Kantzer, A., Gillberg, C., & Billstedt, E. (2021). The road to diagnosis and treatment in girls and boys with ADHD - gender differences in the diagnostic process. *Nordic Journal of Psychiatry*, 75(4), 301-305.
- Krepel, N., Egtberts, T., Sack, A. T., Heinrich, H., Ryan, M., & Arns, M. (2020). A multicenter effectiveness trial of QEEG-informed neurofeedback in ADHD: Replication and treatment prediction. *NeuroImage. Clinical*, 28, 102399. <https://doi.org/10.1016/j.nicl.2020.102399>
- Laidi, C., Levenes, C., Suarez-Perez, A., Février, C., Durand, F., Bouaziz, N., & Januel, D. (2020). Cognitive Impact of Cerebellar Non-invasive Stimulation in a Patient With Schizophrenia. *Frontiers in psychiatry*, 11, 174. <https://doi.org/10.3389/fpsy.2020.00174>
- Lee, G. J., & Suhr, J. A. (2019). Expectancy Effects on Self-Reported Attention-Deficit/Hyperactivity Disorder Symptoms in Simulated Neurofeedback: A Pilot Study. *Archives of clinical neuropsychology : the official journal of the National Academy of Neuropsychologists*, 34(2), 200–205. <https://doi.org/10.1093/arclin/acy026>
- Lefaucheur, J. P., Antal, A., Ayache, S. S., Benninger, D. H., Brunelin, J., Cogiamanian, F., Cotelli, M., De Ridder, D., Ferrucci, R., Langguth, B., Marangolo, P., Mylius, V., Nitsche, M. A., Padberg, F., Palm, U., Poulet, E., Priori, A., Rossi, S., Schecklmann, M., Vanneste, S., ... Paulus, W. (2017). Evidence-based guidelines on the therapeutic use of transcranial direct current stimulation (tDCS). *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology*, 128(1), 56–92. <https://doi.org/10.1016/j.clinph.2016.10.087>
- Lefaucheur, J. P., Aleman, A., Baeken, C., Benninger, D. H., Brunelin, J., Di Lazzaro, V., Filipović, S. R., Grefkes, C., Hasan, A., Hummel, F. C., Jääskeläinen, S. K., Langguth, B., Leocani, L., Londero, A., Nardone, R., Nguyen, J. P., Nyffeler, T., Oliveira-Maia, A. J., Oliviero, A., Padberg, F., ... Ziemann, U. (2020). Evidence-based guidelines on the therapeutic use of repetitive transcranial magnetic stimulation (rTMS): An update (2014-2018). *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology*, 131(2), 474–528. <https://doi.org/10.1016/j.clinph.2019.11.002>
- Logemann, H. N., Lansbergen, M. M., Van Os, T. W., Böcker, K. B., & Kenemans, J. L. (2010). The effectiveness of EEG-feedback on attention, impulsivity and EEG: a sham feedback controlled study. *Neuroscience letters*, 479(1), 49–53. <https://doi.org/10.1016/j.neulet.2010.05.026>

- Lubar, J. F., Swartwood, M. O., Swartwood, J. N., & O'Donnell, P. H. (1995). Evaluation of the effectiveness of EEG neurofeedback training for ADHD in a clinical setting as measured by changes in TOVA scores, behavioral ratings, and WISC-R performance. *Biofeedback and Self-regulation*, 20, 83-99.
- Martins, P., Luzia, R. W. S., Filho, J. A. P., Welsh, K. S., Fuzikawa, C., Nicolato, R., Alemão, M. M., Gonçalves, M. A., Cavalheiro, J. C., Ávila, I. D., & Veiga, R. T. (2024). Prevalence and factors associated with burnout among health professionals of a public hospital network during the COVID-19 pandemic. *PLoS one*, 19(4), e0298187. <https://doi.org/10.1371/journal.pone.0298187>
- Mayer, K., Blume, F., Wyckoff, S. N., Brokmeier, L. L., & Strehl, U. (2016). Neurofeedback of slow cortical potentials as a treatment for adults with Attention Deficit-/Hyperactivity Disorder. *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology*, 127(2), 1374–1386. <https://doi.org/10.1016>
- Mizuno, Y., Cai, W., Supekar, K., Makita, K., Takiguchi, S., Silk, T. J., Tomoda, A., & Menon, V. (2023). Methylphenidate Enhances Spontaneous Fluctuations in Reward and Cognitive Control Networks in Children With Attention-Deficit/Hyperactivity Disorder. *Biological psychiatry. Cognitive neuroscience and neuroimaging*, 8(3), 271–280. <https://doi.org/10.1016/j.bpsc.2022.10.001>
- Niederhofer H. (2011). Additional biological therapies for attention-deficit hyperactivity disorder: repetitive transcranial magnetic stimulation of 1 Hz helps to reduce methylphenidate. *Clinics and practice*, 2(1), e8. <https://doi.org/10.4081/cp.2012.e8>
- Nigl, A. J., & Jackson, B. (1979). Electromyograph biofeedback as an adjunct to standard psychiatric treatment. *The Journal of clinical psychiatry*, 40(10), 433–436.
- Paz, Y., Friedwald, K., Levkovitz, Y., Zangen, A., Alyagon, U., Nitzan, U., Segev, A., Maoz, H., Koubi, M., & Bloch, Y. (2018). Randomised sham-controlled study of high-frequency bilateral deep transcranial magnetic stimulation (dTMS) to treat adult attention hyperactive disorder (ADHD): Negative results. *The world journal of biological psychiatry : the official journal of the World Federation of Societies of Biological Psychiatry*, 19(7), 561–566. <https://doi.org/10.1080/15622975.2017.1282170>
- Pigott, H. E., Cannon, R., & Trullinger, M. (2021). The Fallacy of Sham-Controlled Neurofeedback Trials: A Reply to Thibault and Colleagues (2018). *Journal of attention disorders*, 25(3), 448–457. <https://doi.org/10.1177/1087054718790802>
- Richter MM, Ehlis AC, Jacob CP, Fallgatter AJ. (2007). Cortical excitability in adult patients with attention-deficit/hyperactivity disorder (ADHD). *Neurosci Lett* ; 419(2):137–41 <http://dx.doi.org/10.1016/j.neulet.2007.04.024>.

- Ryoo, M., & Son, C. (2015). Effects of Neurofeedback Training on EEG, Continuous Performance Task (CPT), and ADHD Symptoms in ADHD-prone College Students. *Journal of Korean Academy of Nursing*, 45(6), 928–938. <https://doi.org/10.4040/jkan.2015.45.6.928>
- Ros, T., Enriquez-Geppert, S., Zotev, V., Young, K. D., Wood, G., Whitfield-Gabrieli, S., Wan, F., Vuilleumier, P., Vialatte, F., Van De Ville, D., Todder, D., Surmeli, T., Sulzer, J. S., Strehl, U., Sterman, M. B., Steiner, N. J., Sorger, B., Soekadar, S. R., Sitaram, R., Sherlin, L. H., ... Thibault, R. T. (2020). Consensus on the reporting and experimental design of clinical and cognitive-behavioural neurofeedback studies (CRED-nf checklist). *Brain : a journal of neurology*, 143(6), 1674–1685. <https://doi.org/10.1093/brain/awaa009>
- Schönenberg, M., Wiedemann, E., Schneidt, A., Scheeff, J., Logemann, A., Keune, P. M., & Hautzinger, M. (2017). Neurofeedback, sham neurofeedback, and cognitive-behavioural group therapy in adults with attention-deficit hyperactivity disorder: a triple-blind, randomised, controlled trial. *The lancet. Psychiatry*, 4(9), 673–684. [https://doi.org/10.1016/S2215-0366\(17\)30291-2](https://doi.org/10.1016/S2215-0366(17)30291-2)
- Schönenberg, M., Weingärtner, A. L., Weimer, K., & Scheeff, J. (2021). Believing is achieving - On the role of treatment expectation in neurofeedback applications. *Progress in neuro-psychopharmacology & biological psychiatry*, 105, 110129. <https://doi.org/10.1016/j.pnpbp.2020.110129>
- Senova, S., Rabu, C., Beaumont, S., Michel, V., Palfi, S., Mallet, L., Domenech, P. (2019). Stimulation du nerf vague dans le traitement de la dépression. Vagus nerve stimulation and depression. *La Presse Médicale*. 48(12), 1507-1519. <https://doi.org/10.1016/j.lpm.2019.10.019>
- Shaw, P., Stringaris, A., Nigg, J., & Leibenluft, E. (2014). Emotion dysregulation in attention deficit hyperactivity disorder. *The American journal of psychiatry*, 171(3), 276–293. <https://doi.org/10.1176/appi.ajp.2013.13070966>
- Sonuga-Barke, E. J., Brandeis, D., Cortese, S., Daley, D., Ferrin, M., Holtmann, M., Stevenson, J., Danckaerts, M., van der Oord, S., Döpfner, M., Dittmann, R. W., Simonoff, E., Zuddas, A., Banaschewski, T., Buitelaar, J., Coghill, D., Hollis, C., Konofal, E., Lecendreux, M., Wong, I. C., ... European ADHD Guidelines Group (2013). Nonpharmacological interventions for ADHD: systematic review and meta-analyses of randomized controlled trials of dietary and psychological treatments. *The American journal of psychiatry*, 170(3), 275–289. <https://doi.org/10.1176/appi.ajp.2012.12070991>
- Stark, R., Bauer, E., Merz, C. J., Zimmermann, M., Reuter, M., Plichta, M. M., Kirsch, P., Lesch, K. P., Fallgatter, A. J., Vaitl, D., & Herrmann, M. J. (2011). ADHD related behaviors are associated with brain activation in the reward system. *Neuropsychologia*, 49(3), 426–434. <https://doi.org/10.1016/j.neuropsychologia.2010.12.012>

- Tajik-Parvinchi, D., Wright, L., & Schachar, R. (2014). Cognitive Rehabilitation for Attention Deficit/Hyperactivity Disorder (ADHD): Promises and Problems. *Journal of the Canadian Academy of Child and Adolescent Psychiatry = Journal de l'Academie canadienne de psychiatrie de l'enfant et de l'adolescent*, 23(3), 207–217.
- Thompson, L., & Thompson, M. (1998). Neurofeedback combined with training in metacognitive strategies: effectiveness in students with ADD. *Applied psychophysiology and biofeedback*, 23(4), 243–263. <https://doi.org/10.1023/a:1022213731956>
- Tikka, S. K., Siddiqui, M. A., Garg, S., Patojoshi, A., & Gautam, M. (2023). Clinical Practice Guidelines for the Therapeutic Use of Repetitive Transcranial Magnetic Stimulation in Neuropsychiatric Disorders. *Indian journal of psychiatry*, 65(2), 270–288. https://doi.org/10.4103/indianjpsychiatry.indianjpsychiatry_492_22
- Ustohal, L., Prikryl, R., Kucerova, H. P., Sisrova, M., Stehnova, I., Venclikova, S., Vrzalova, M., & Ceskova, E. (2012). Emotional side effects after high-frequency rTMS of the right dorsolateral prefrontal cortex in an adult patient with ADHD and comorbid depression. *Psychiatria Danubina*, 24(1), 102–103.
- Veilahti, A. V. P., Kovarskis, L., & Cowley, B. U. (2021). Neurofeedback Learning Is Skill Acquisition but Does Not Guarantee Treatment Benefit: Continuous-Time Analysis of Learning-Curves From a Clinical Trial for ADHD. *Frontiers in human neuroscience*, 15, 668780. <https://doi.org/10.3389/fnhum.2021.668780>
- Verghese C, Abdijadid S. (Updated 2023). Methylphenidate. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan. <https://www.ncbi.nlm.nih.gov/books/NBK482451/>
- Villemonteix, T., Institut de psychiatrie et neurosciences, Université Sorbonne Paris Cité, Université libre de Bruxelles, Philip Gorwood, & Isabelle Massat. (2015). *Neuropsychological Heterogeneity in Attention Deficit / Hyperactivity Disorder: Factors Influencing the Disorder's Structural Correlates*, <https://tel.archives-ouvertes.fr/tel-01192855>.
- Vos M, Hartman CA. (2022). The decreasing prevalence of ADHD across the adult lifespan confirmed. *J Glob Health*;12:03024. <http://dx.doi.org/10.7189/jogh.12.03024>.
- Weaver, L., Rostain, A. L., Mace, W., Akhtar, U., Moss, E., & O'Reardon, J. P. (2012). Transcranial magnetic stimulation (TMS) in the treatment of attention-deficit/hyperactivity disorder in adolescents and young adults: a pilot study. *The journal of ECT*, 28(2), 98–103. <https://doi.org/10.1097/YCT.0b013e31824532c8>
- Woods AJ, Antal A, Bikson M, Boggio PS, Brunoni AR, Celnik P, et al. A technical guide to tDCS, and related non-invasive brain stimulation tools. *Clin Neurophysiol* 2016;127:1031-48.
- Zilverstand, A., Sorger, B., Slaats-Willemse, D., Kan, C. C., Goebel, R., & Buitelaar, J. K. (2017). fMRI Neurofeedback Training for Increasing Anterior Cingulate Cortex Activation in

Adult Attention Deficit Hyperactivity Disorder. An Exploratory Randomized, Single-Blinded Study. *PloS one*, 12(1), e0170795. <https://doi.org/10.1371/journal.pone.0170795>

Author Manuscript