



# Results of Neurofeedback in Treatment of Children with ADHD: A Systematic Review of Randomized Controlled Trials

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## Abstract

Attention-deficit/hyperactivity disorder (ADHD) is one of the most prevalent disorders in children and adolescents. Neurofeedback, a nonpharmaceutical treatment, has shown promising results. To review the evidence of efficacy of neurofeedback as a treatment for children and adolescents with ADHD. A systematic review of the specific scientific studies published in 1995–2021, identifying and analyzing randomized controlled trials (RCT). A total of 1636 articles were identified and 165 met inclusion criteria, of which 67 were RCTs. Neurofeedback training was associated with significant long-term reduction in symptoms of ADHD. Though limitations exist regarding conclusions about the specific effects of neurofeedback, the review documents improvements in school, social, and family environments.

**Keywords** Neurofeedback · Treatment · ADHD · Children

## Introduction

Attention-deficit/hyperactivity disorder (ADHD) is characterized by a persistent pattern of inattention and/or hyperactivity and impulsivity which affects a child's social, occupational or academic functioning. Severity of symptoms varies from light to moderate to severe and clinical presentations include predominantly inattention, hyperactivity/impulsivity or a combination of them (American Psychiatric Association, 2013). There is no single or universal treatment for this disorder. Danielson et al. (2018) described the range of treatments in A National Description of Treatment among United States Children and Adolescents with ADHD, which followed up parents of children (4–17) with ADHD starting in 2011 who received four main types of treatment: medication, psychosocial intervention, school support and

alternative treatments. Of these children, 67% received the first three types of treatment and 7% none. Psychological treatments included training in social skills (39%), training for parents (31%), peer intervention (30%), cognitive behavioral therapy (20%), alternative treatments (e.g., dietary supplements) (9%) and neurofeedback (11%). Neurofeedback is one of the neuroregulation techniques (Gevensleben et al., 2014), which are posited to produce changes in the subject's neural activity. Research on neurofeedback has demonstrated an irregular EEG pattern (reduced activity of beta waves and increased theta) in most children with ADHD (Janssen et al., 2017; Loo & Makeig, 2012; Snyder & Hall, 2006). Theta/beta ratio (TBR) training and slow cortical potential training (SCP) have received the most support and evidence for treatment of ADHD (Gevensleben et al., 2014; Monastra et al., 2005). In view of the sometimes contradictory data on neurofeedback treatment, researchers endorse the need for more randomized controlled trials (RCT).

One of the first studies that analyzed the efficacy of neurofeedback for ADHD treatment was done by Rossiter and La Vaque (1995), who used a group design to compare neurofeedback with psychostimulants. Lubar et al. (1995), compared neurofeedback with treatment using methylphenidate (MPH) in a clinic setting. In a case series by Thompson and Thompson (1998), neurofeedback was applied along with other learning strategies and showed significant improvement on various evaluation scales including IQ. Reviews

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and meta-analyses by Gaviria et al. (2014), Lofthouse et al. (2012) and Micoulaud-Franchi et al. (2014), concluded that application of different forms of neurofeedback were effective. Their beneficial effects are maintained in some cases up to 6 months after treatment (Arns et al., 2009; Meisel et al., 2013; Steiner et al., 2014a, 2014b), in others, from 2 to 12 months posttreatment (Van Doren et al., 2019) and in 1, for 2 years (Gani et al., 2008). The meta-analysis by Riesco-Matías et al. (2021) supported the efficacy of neurofeedback and proposed a relationship between what is learned by the subject during neurofeedback training, ADHD symptoms and neurophysiological measurements.

Among the publications reporting on RCT, Lubar et al. (1995) found significant improvement post-training in TOVA, ADDES and WISC-R performance. Vollebregt et al. (2014) found no difference between treatment groups with neurofeedback and a placebo, but Geladé et al. (2018) did conclude that the neurofeedback group had better results than the one with physical activity. Rubia et al. (2019) also found improvement in the two neurofeedback treatment groups that they studied. Concerning evidence of neurofeedback as a treatment for ADHD, some studies have concluded that neurofeedback is “effective” as a treatment for ADHD (Arns et al., 2009), “probably effective” (Lofthouse et al., 2012) or “possibly effective” (Storebø et al., 2011). Along the same line as Monastra et al. (2005), the review by Sampedro Baena et al. (2021) suggested that as there is no conclusive RCT research, more RCTs need to be published.

The objective of this study was to review the evidence regarding the efficacy of neurofeedback as a treatment for children and adolescents with ADHD by means of a systematic review of RCTs. Scientific productivity, reflected in growth in the number of studies, as well as its geographic distribution and the journals that published the studies during the 27 year study period, were analyzed for this purpose.

## Methods

This systematic review was performed following the guidelines of the PRISMA Declaration (Page et al., 2021). A search was made in the PscINFO and Medline (PubMed) databases on December 1, 2021. The search strategy, including the keywords, Boolean operators and search fields, was the following:

Title or Abstract = ADHD AND (“Attention Deficit Disorder” OR “Attention Deficit Disorder with Hyperactivity”); AND Title or Abstract = Neurofeedback OR “EEG Biofeedback”; AND Title or Abstract = Treatment; AND Title or Abstract = “Randomized Controlled Trial”.

The search period delimited was from January 1995 to December 2021. This period was selected because most of the published evidence available on-line concerning the use

of neurofeedback for the treatment of ADHD dates from 1995, though Lubar published a case study concerning effective treatment of a hyperkinetic child using neurofeedback as early as 1976.

The inclusion criteria were the following: (a) articles published in peer-reviewed journals that included neurofeedback as a treatment for ADHD; (b) participants aged 6–18; (c) participants with primary diagnosis ADHD (as inclusion criteria in the articles), including subtypes/clinical presentations, regardless of the diagnostic manual used; and (d) articles in which neurofeedback had been administered as the only treatment option and/or combined with other treatments (medication, behavioral therapy, etc.).

The exclusion criteria were: (a) papers and chapters in books on the subject, not published in peer-reviewed journals; (b) neurofeedback concept, descriptive and/or explanatory articles; (c) studies with participants not diagnosed with ADHD or with comorbid disorders/alterations (physical or psychological) along with this disorder, such as obsessive–compulsive disorder, tics or intellectual disability, among others; (d) articles replicating or commenting on previous publications; (e) duplicate studies in the databases (eliminated in one of them); (f) other types of EEG; and (g) publications that refer to neurofeedback as a treatment but not as the main intervention of the study.

Neither publication language nor country of origin of authors was considered a criterion for exclusion. Nor were studies excluded because of the measures used (attention, behavior control, etc.), the results, sample size, treatment conditions or neurofeedback application procedure.

Study selection was based on inclusion and exclusion criteria when examining the titles, abstracts, and having surpassed that stage, review of the complete text to evaluate their pertinence according to the specified criteria. To ensure evaluation reliability, 20% of the articles were chosen at random to be analyzed independently by a second examiner who did not know the first examiner’s decision. Agreement between reviewers on the inclusion of articles was estimated using Cohen’s kappa, finding a coefficient of 0.9, which shows good agreement (Hallgren, 2012).

Once the studies had been selected using the criteria mentioned, and in view of the possibility that there could be some publication not included in the databases reviewed, the procedure in Van Doren et al. (2019) and Willis et al. (2011) was followed, making a manual search in the references listed. By following this protocol before the review, possible risk of bias was reduced. In the table synthesizing results, publications included in the database search are marked with an \* and those included in the complementary search are marked .

Data extraction was done using a table created for the purpose that included the main bibliometric characteristics of the study (authors, year of publication, journal, author

country of origin), description of the study participants (sample size, age range and gender distribution), as well as study methodology characteristics (study design, number of sessions and length of intervention and evaluation instruments) and the main findings concerning neurofeedback. Extraction table adequacy was checked in a pilot test and was reviewed by the whole research team. To ensure data extraction quality, 20% of the records were selected and were reviewed by a third-party professional not involved in the extraction. The result showed a negligible number of discrepancies that did not affect the conclusions derived.

## Results

At first, a total of 1636 publications were identified that met the descriptors: 276 (17%) publications in PsycINFO and 1360 (83%) in PubMed. After eliminating duplicates and screening for time period and age, 216 publications remained, of which only 165 met the inclusion criteria. This process is shown in a PRISMA flow diagram in Fig. 1.

After the search in the lists of references, 53 more articles were included, for a total of 165 articles that met the criteria mentioned. Thus, 76% of the studies identified in PsycINFO and 43% in PubMed were included. That is over 65% (67%) of the studies originally selected.

Of the studies selected (Table 1) 67 were RCTs. The historical evolution of the scientific productivity was examined, considering country of origin and journals where they were published. When the historical evolution of the data was

analyzed (Fig. 2) in 4-year range groups, growth in number of publications is observed. Geographically (Fig. 3), the studies were concentrated in Germany (16 studies), the Netherlands (11) and the United States (11), while the rest of the countries contributed three or fewer publications. Finally, with regard to the journals containing the RCT (Fig. 4), 42 different journals were identified, in which the largest number were in the European Journal of Child & Adolescent Psychiatry (7), Journal of Attention Disorders (4) and BMC Psychiatry (4), which contained the highest number of publications.

The detailed analysis of the studies reviewed may be seen in Table 2, showing the study author/s, year, country, participants (sample size, age, sex, ADHD subtypes), treatment, therapeutic sessions (total number of sessions, periodicity and duration), evaluation instruments and results, etc. Table 3 shows the instruments, evaluation techniques and treatment. There was only one possible case of bias in a study which, although it apparently met all the criteria for inclusion, was not included, since it did not specify whether the participants had other comorbid disorders.

The publications selected were analyzed for the following variables: participants, number of neurofeedback sessions and their duration, and neurofeedback protocols applied. The results showed that overall, 4980 children received neurofeedback. Of the total studies included ( $n = 67$ ), 30 (45% included a sample size  $\leq 50$  participants, and 37 (55%)  $> 50$ . Similarly, 2041 treatment sessions were given, lasting about 20–60 min. The TBR and SCP training protocols were used the most (Table 2).

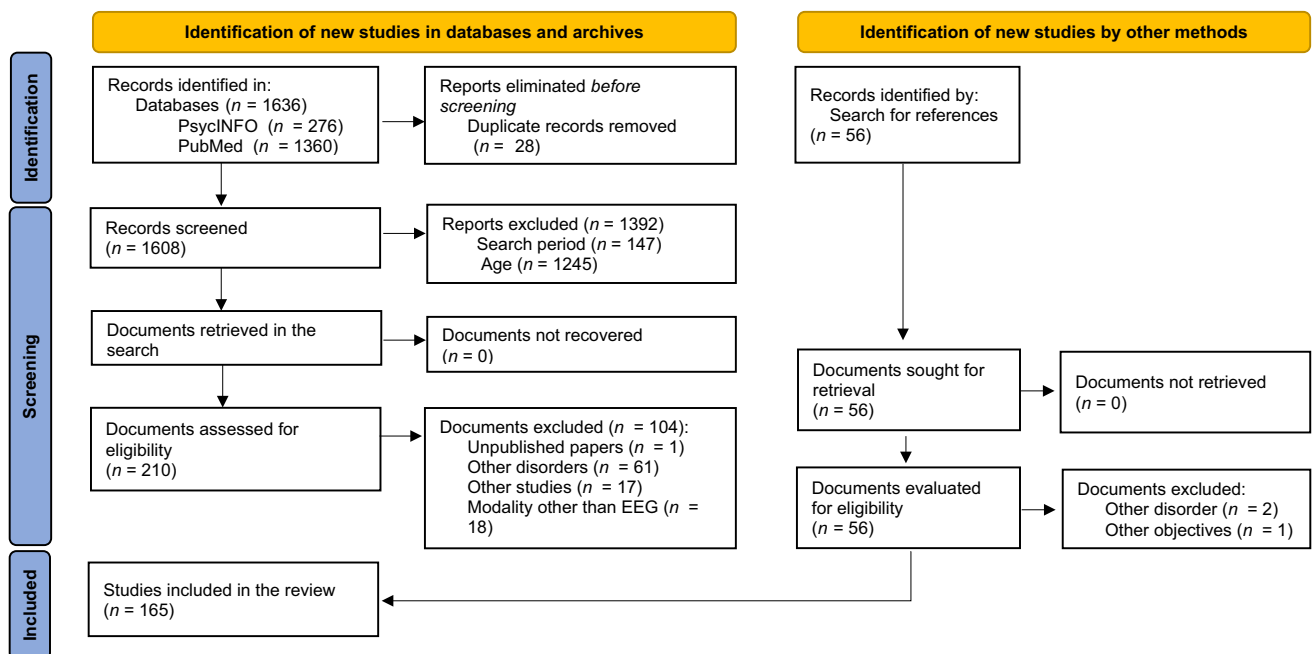


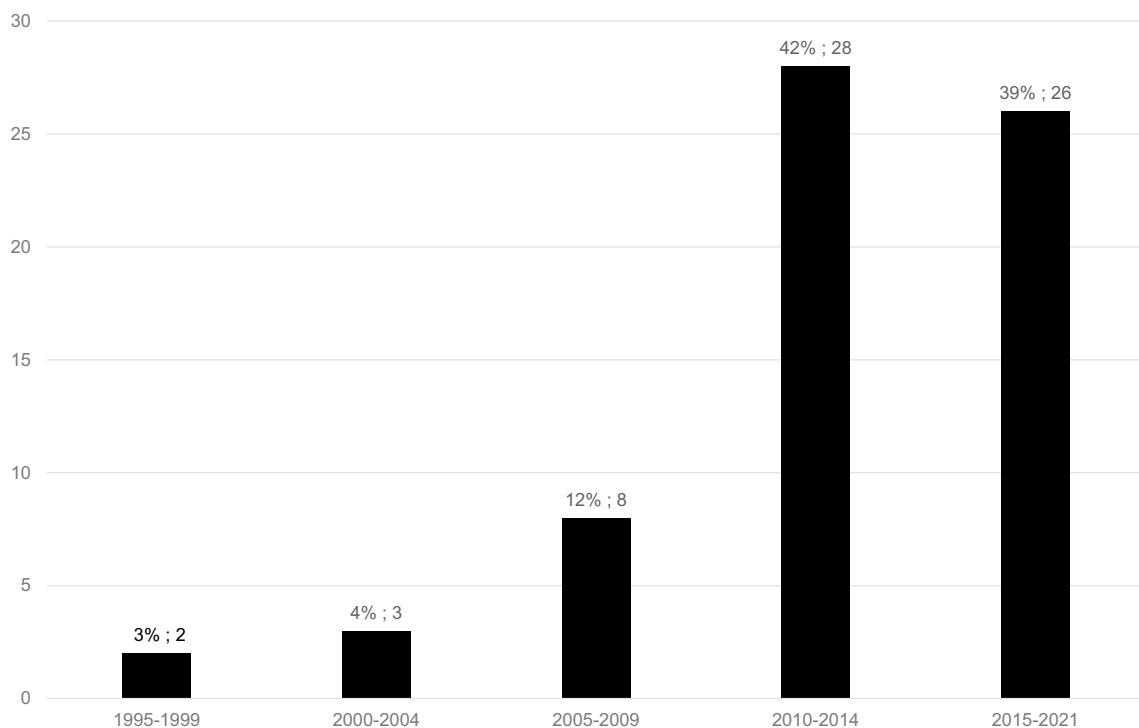
Fig. 1 PRISMA 2020 flow diagram for search in databases and other sources. Adapted from Page et al. (2021)

**Table 1** Year, journal and country of each randomized controlled trial included

| Year                             | Journal   | Country     |
|----------------------------------|---|-------------|
| Lubar et al. (1995)              | Biofeedback and Self-Regulation   | USA         |
| Linden et al. (1996)             | Biofeedback and Self-Regulation   | USA         |
| Cho et al. (2002)                | Studies in Health Technology and Informatics                                | Korea       |
| Heywood and Beale (2003)         | Journal of Attention Disorders  | New Zealand |
| Cho et al. (2004)                | CyberPsychology and Behavior  | Korea       |
| Zhonggui et al. (2005)           | Journal of Huazhong University of Science and Technology [Medical Sciences] | China       |
| Lévesque et al. (2006)           | Neuroscience Letter   | Canada      |
| Beauregard and Lévesque (2006)   | Applied Psychophysiology and Biofeedback                                    | Canada      |
| Leins et al. (2007)              | Applied Psychophysiology and Biofeedback                                    | Germany     |
| Gani et al. (2008)               | International Journal of Bioelectromagnetism                                | Germany     |
| Holtmann et al. (2009)           | Kindheit und Entwicklung  | Germany     |
| Gevensleben et al. (2009a)       | Journal of Child Psychology and Psychiatry                                  | Germany     |
| Gevensleben et al. (2009b)       | International Journal of Psychophysiology                                   | Germany     |
| Perreau-Linck et al. (2010)      | Journal of Neurotherapy   | Canada      |
| Bakhshayesh et al. (2010)        | Psychological Research  | Germany     |
| Gevensleben et al. (2010a)       | European Child & Adolescent Psychiatry                                      | Germany     |
| Gevensleben et al. (2010b)       | Zeitschrift für Kinder und Jugendpsychiatrie Psychotherapie                 | Germany     |
| DeBeus and Kaiser (2011)         | Neurofeedback and Neuromodulation Techniques and Applications               | USA         |
| Lansbergen et al. (2011)         | Journal of Neural Transmission  | Netherlands |
| Wangler et al. (2011)            | Clinical Neurophysiology  | Germany     |
| Steiner et al. (2011)            | Clinical Pediatrics   | USA         |
| Bakhshayesh et al. (2011)        | European Child & Adolescent Psychiatry                                      | USA         |
| Duric et al. (2012)              | BMC Psychiatry  | Norway      |
| Liechti et al. (2012)            | Clinical Neurophysiology  | Switzerland |
| Russell-Chapin et al. (2013)     | Journal of Neurotherapy   | USA         |
| Arnold et al. (2013)             | Journal of Attention Disorders  | USA         |
| Kerson (2013)                    | Journal of Attention Disorders  | USA         |
| van Dongen-Boomsma et al. (2013) | Journal of Clinical Psychiatry  | Netherlands |
| Li et al. (2013)                 | Swiss Medical Weekly  | China       |
| Meisel et al. (2013)             | Biological Psychology   | Spain       |
| Ogrim and Hestad (2013)          | Journal of Child and Adolescent Psychopharmacology                          | Norway      |
| Vollebregt et al. (2014)         | Journal of Child Psychology and Psychiatry                                  | Netherlands |
| Maurizio et al. (2014)           | Biological Psychology   | Switzerland |
| Gevensleben et al. (2014)        | Brain Topography  | Germany     |
| Steiner et al. (2014b)           | Journal of Developmental and Behavioral Pediatrics                          | USA         |
| Steiner et al. (2014a)           | Pediatrics  | USA         |
| Holtmann et al. (2014a)          | BMC Psychiatry  | Germany     |
| He et al. (2014)                 | Zhongguo Zhen Jiu   | China       |
| Bink et al. (2014)               | European Child & Adolescent Psychiatry                                      | Netherlands |
| Duric et al. (2014)              | Neuropsychiatric Disease and Treatment                                      | Norway      |
| Christiansen et al. (2014)       | Frontiers in Human Neuroscience   | Germany     |
| van Dongen-Boomsma et al. (2015) | Tijdschrift voor Psychiatrie  | Netherlands |
| Keith et al. (2015)              | Psychology of Addictive Behaviors   | USA         |
| Bink et al. (2015)               | The Journal of Clinical Psychiatry  | Netherlands |
| Moreno-García et al. (2015)      | International Journal of Clinical and Health Psychology                     | Spain       |
| Janssen et al. (2016)            | Journal of Child and Adolescent Psychopharmacology                          | Netherlands |
| Hasslinger et al. (2016)         | Translational Developmental Psychiatry                                      | Sweden      |
| Geladé et al. (2016)             | The Journal of Clinical Psychiatry  | Netherlands |
| Moreno-García et al. (2019)      | Journal of Attention Disorders  | Spain       |

**Table 1** (continued)

| Year   | Journal  | Country        |
|--|--|----------------|
| Blume et al. (2017)                          | Trials   | Germany        |
| Mohagheghi et al. (2017)                     | BioMed Research International                                      | Iran           |
| Lee and Jung (2017)                          | Asian Journal of Psychiatry  | Korea          |
| Strehl et al. (2017)                         | Frontiers in Human Neuroscience                                    | Germany        |
| Geladé et al. (2017)                         | European Child & Adolescent Psychiatry                             | Netherlands    |
| Janssen et al. (2017)                        | European Child & Adolescent Psychiatry                             | Netherlands    |
| Alegria et al. (2017)                        | Human Brain Mapping  | United Kingdom |
| Johnstone et al. (2017)                      | International Journal of Psychophysiology                          | Australia      |
| Duric et al. (2017)                          | Nordic Journal of Psychiatry                                       | Norway         |
| Döpfner et al. (2017)                        | BMC Psychiatry   | Germany        |
| Geladé et al. (2018)                         | European Child & Adolescent Psychiatry                             | Netherlands    |
| Minder et al. (2018)                         | European Child & Adolescent Psychiatry                             | Switzerland    |
| Rubia et al. (2019)                          | NeuroImage   | USA            |
| Bioulac et al. (2019)                        | BMC Psychiatry   | France         |
| Dobrakowski and Lebecka (2020)               | Clinical EEG and Neuroscience                                      | Poland         |
| Purper-Ouakil et al. (2021)                  | Journal of Child Psychology and Psychiatry                         | France         |
| The Neurofeedback Collaborative Group (2021) | Journal of the American Academy of Child and Adolescent Psychiatry | USA            |
| Aggensteiner et al. (2021)                   | Biological Psychology  | Germany        |



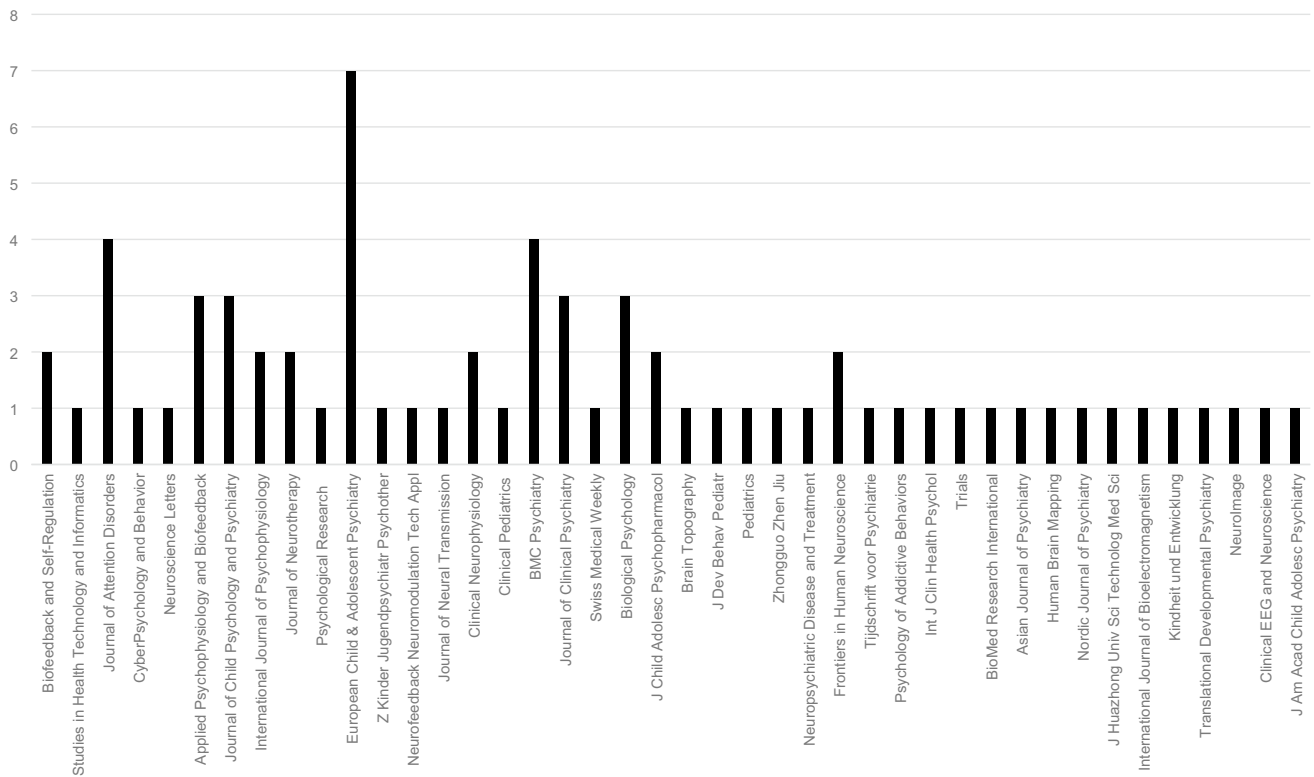
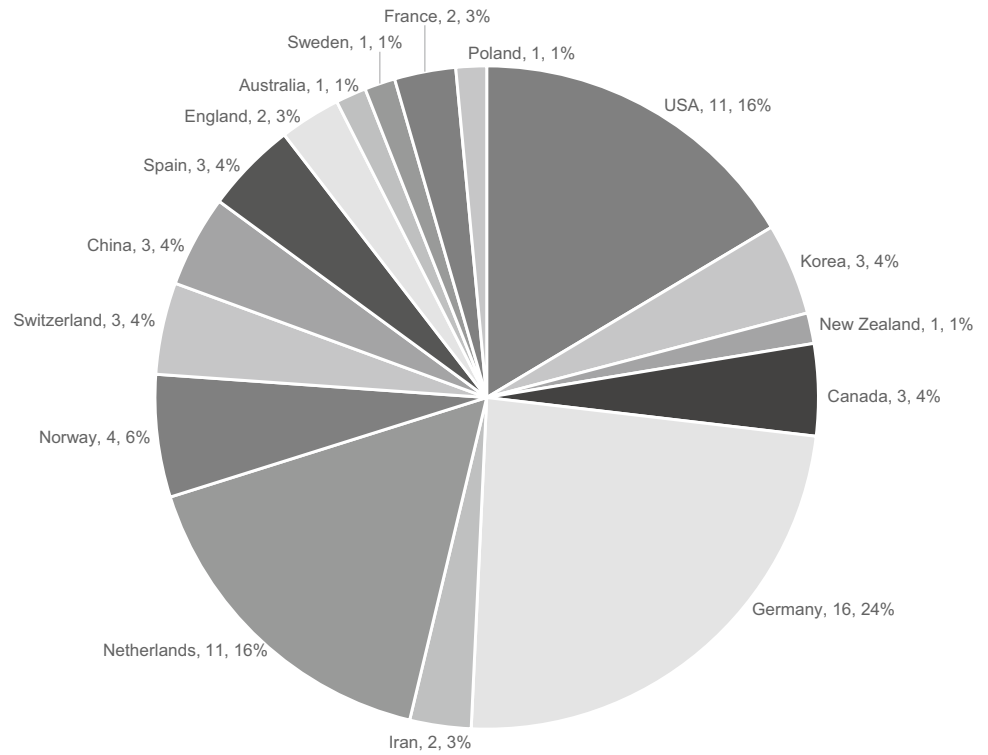
**Fig. 2** Historical evolution by period of years of studies with randomized controlled trials included in this review

After the articles had been reviewed, in general, neurofeedback was found to produce beneficial effects, such as reduction in measured core ADHD symptoms of inattention, hyperactivity and/or impulsivity, intelligence and other

altered behaviors, like opposition and physical aggression, social and school variables.

Specifically concerning improvement in core ADHD measurements, the studies by Aggensteiner et al. (2021),

**Fig. 3** Geographic distribution by country of origin of studies with randomized controlled trial design included in this review



**Fig. 4** Journals that have published at least one randomized controlled trial during the period reviewed

**Table 2** Synthesis of studies reviewed: randomized controlled trials

| Author/s (year)       | Participants |                  | Design | Total sessions/wks (duration/session) | Evaluation instruments   | Neurofeedback results  |
|-----------------------|--------------|------------------|--------|---------------------------------------|--------------------------|--|
|                       | <i>n</i>     | Age (sex)        |        |                                       |                          |  |
| Lubar et al. (1995)*  | 23           | 8–19 (35 M; 6 F) | –      | 40ses.8–10 wks (60')                  | TOVA.ADDRES. WISC-R      | Comparing pre-post treatment, neurofeedback training showed significant differences in the three studies:<br>1. Significant improvement in T.O.V.A. performance in participants showing significant EEG changes in comparison with subjects without changes ( $t = 2.99, p < .01$ )<br>2. Significant clinical improvement in behavior ratings (measured by parents) in hyperactivity ( $t = -4.60, p < .0001$ ), impulsivity ( $t = -6.596, p < .001$ ), and inattention ( $t = -4.474, p < .001$ )<br>3. Significant increase in WISC-R performance, in IQ scores (verbal: $t = -3.65, p < .005$ ; full scale: $t = -3.68, p < .005$ and performance: $t = -2.18, p < .05$ ) |
| Linden et al. (1996)* | 18           | 5–15             | –      | 40ses.24 wks (45')                    | K-BIT.IOWA-Conners. SNAP | The neurofeedback group showed post-treatment improvements of clinical significance. A significant increase of a mean of 9 points was observed on the K-Bit IQ Composite compared to the waiting list ( $p < .05$ )  |

Table 2 (continued)

| Author/s (year)           | Participants |            | Design | Total sessions/wks<br>(duration/session) | Evaluation instruments              | Neurofeedback results   |
|---------------------------|--------------|------------|--------|--|-------------------------------------|---|
|                           | <i>n</i>     | Age (sex)  |        |  |                                     |   |
| Cho et al. (2002)*        | 50           | 14–18      | –      | 8 ses. 24 wks (20')                      | CPT                                 | Significant post-treatment improvement was obtained in CPT (more correct answers) in both groups ( $F(1,32) = 93.760$ , $p < .01$ ). Experimental groups improved more than placebo groups ( $F(1,32) = 4.193$ , $p < .05$ ). Neurofeedback groups showed more improvement than cognitive training groups ( $F(1,32) = 3.121$ , $p < .10$ ) |
| Heywood and Beale (2003)* | 7            | 7–12 (7 M) | –      | 60 ses. 24 wks (20–40')                  | ADHD-RS, CAP, CCT, CPT, PAL-T, CBCL | Both groups showed increased clinical improvements. Placebo group showed relatively increased improvements, with small effect size ( $d = 0.24$ ), in some cases  |
| Cho et al. (2004)*        | 28           | 14–18 (M)  | –      | 8 ses. 2 wks (20')                       | CPT                                 | Significant increase ( $p < .01$ ) in selective attention, better information management and less impulsivity in neurofeedback groups. Comparing VR and non-VR groups, the effects group ( $F(1,16) = 10.392$ , $p < 0.01$ ) and time ( $F(1,16) = 14.125$ , $p < 0.01$ ) were significant  |



**Table 2** (continued)

| Author/s (year)         | Participants |   | Design   | Total sessions/wks<br>(duration/session) | Evaluation instruments | Neurofeedback results  |
|-------------------------|--------------|---|--|--|------------------------|--|
|                         | <i>n</i>     | Age (sex)<br>Subtype  |  |  |                        |  |
| Zhonggui et al. (2005)* | 60           | > 6<br>I ( <i>n</i> = 20); H ( <i>n</i> = 20); C ( <i>n</i> = 20) | 1 Group: Neurofeedback (SCP; SMR)  | 40ses. 20 wks/2 (20')                    | IVA                    | Neurofeedback showed significant clinical improvement in overall symptoms. IVA indexes resulted in significant improvement ( <i>p</i> < .001)  |
| Lévesque et al. (2006)* | 20           | 8–12 (16 M; 4 F)  | 2 Groups: 1. Neurofeedback (SMR; TBR) ( <i>n</i> = 15). 2. Control ( <i>n</i> = 5) | 40ses. 13.5 wks/3 (60')                  | WISC-R.IVA.CPRS-R      | Neurofeedback resulted in brain activity changes (significant activation of the right ACC found only in the neurofeedback group). Neurofeedback led to clinical improvements by normalizing selective attention and response inhibition in children with ADHD compared to the control group. Comparing pre-post treatment measures, neurofeedback group showed significant increase on the Digit Span ( <i>p</i> < .05), IVA scores ( <i>p</i> < .005) and significant decrease (measured with the CPRS-R) on inattention ( <i>p</i> < .001) and hyperactivity ( <i>p</i> < .05) |

Table 2 (continued)

| Author/s (year)                  | Participants |                  | Design | Total sessions/wks<br>(duration/session) | Evaluation instruments | Neurofeedback results   |
|----------------------------------|--------------|------------------|--------|--|------------------------|---|
|                                  | <i>n</i>     | Age (sex)        |        |  |                        |   |
| Beauregard and L evesque (2006)* | 2            | 8–12 (16 M; 4 F) | –      | 40ses.13.5 wks/3 (60')                   | WISC-R.IVA,CPRS-R      | Neurofeedback resulted in significant activation of right ACC, left caudate nucleus and left substantia nigra. Comparing pre-post treatment measures, neurofeedback group showed significant increase on the Digit Span ( $p < .05$ ), IVA scores ( $p < .005$ ) and significant decrease (measured with the CPRS-R) on inattention ( $p < .001$ ) and hyperactivity ( $p < .05$ ) resulting in behavioral and attentional improvements |

**Table 2** (continued)

| Author/s (year)      | Participants |                  | Design                                | Total sessions/wks<br>(duration/session) | Evaluation instruments             | Neurofeedback results   |
|----------------------|--------------|------------------|---------------------------------------|--|------------------------------------|---|
|                      | <i>n</i>     | Age (sex)        |                                       |  |                                    |   |
| Leins et al. (2007)* | 38           | 8–13 (32 M; 6 F) | I ( <i>n</i> = 30); H ( <i>n</i> = 8) | 30 ses. 6 wks (60')                      | HAWIK-III, TAP, CRS, ECBI, ADHD-RS | Neurofeedback led to significant improvement in ADHD symptoms, intelligence and other altered behavior maintained 6 months. Neurofeedback showed significant decrease in parental (Inattention: $F(2,68) = 9.15, p = .001$ ; Hyperactivity: $F(2,68) = 10.08, p < .001$ ; CRS: $F(2,62) = 7.75, p = .001$ ) and teachers (Hyperactivity: $F(2,64) = 6.58, p = .003$ ; Impulsivity: $F(2,64) = 5.43, p = .008$ ; Social behavior: $p = .010$ ) ratings over time. Both groups of neurofeedback resulted in significant improvement on IQ performance ( $F(1,35) = 31.11, p = .002$ ) and scale ( $F(1,35) = 11.39, p = .002$ ). None showed significant time $\times$ group interaction nor differences between groups |

Table 2 (continued)

| Author/s (year)         | Participants |  | Design   | Total sessions/wks<br>(duration/session) | Evaluation instruments | Neurofeedback results  |
|-------------------------|--------------|--|--|--|------------------------|--|
|                         | <i>n</i>     | Age (sex)<br>Subtype   |  |  |                        |  |
| Gani et al. (2008)      | 47           | 8–12 (38 M; 9 F)<br>I ( <i>n</i> = 10); H ( <i>n</i> = 1); C<br>( <i>n</i> = 36) | 2 Groups: 1. Neurofeedback<br>(SCP) ( <i>n</i> = 25). 2. Neurofeed-<br>back (TBR) ( <i>n</i> = 22) | 36 wks                                   | TAP, CRS, ECBI         | Clinical outcomes and<br>self-regulations skills<br>were maintained at<br>2 years follow-up in<br>both groups of neuro-<br>feedback. Significant<br>decrease in parental rat-<br>ings over time on meas-<br>ures of inattention ( $F(2, 40) = 16.40, p = .00$ ),<br>( $F(2, 40) = 14.59, p = .00$ ) and CRS ( $F(2, 40) = 8.277, p = .01$ ).<br>None showed significant<br>time $\times$ group interaction<br>nor significant differ-<br>ence between groups |
| Holtmann et al. (2009)* | 34           | 10.3 (31 M; 3 F)<br>I ( <i>n</i> = 20); H ( <i>n</i> = 12); C<br>( <i>n</i> = 2) | 2 Groups: 1. Neurofeedback<br>(theta/beta) ( <i>n</i> = 20). 2. AST<br>( <i>n</i> = 14)            | 20 ses. 10 wks/1 (30')                   | FBB-HKS                | Neurofeedback showed<br>relatively higher<br>effects in comparison.<br>Improvements were<br>reported along groups<br>and time. No sig-<br>nificant differences were<br>reported between them.<br>Improvements in the<br>main ADHD symp-<br>toms were inattention<br>( $d = 0.40$ ), hyperactivity<br>( $d = 0.13$ ) and impulsiv-<br>ity ( $d = 0.14$ )  |

**Table 2** (continued)

| Author/s (year)              | Participants |   | Design  | Total sessions/wks<br>(duration/session) | Evaluation instruments                   | Neurofeedback results   |
|------------------------------|--------------|---|---|--|--|---|
|                              | <i>n</i>     | Age (sex)   |   |  |  |   |
| Gevensleben et al. (2009a)*  | 94           | 8–12 (77 M; 17 F)<br>I ( <i>n</i> =28); C ( <i>n</i> =66) | 2 Groups: 1. Neurofeedback (TBR; SCP). 2. AST                                 | 36ses. 6–8 wks/4–6 (50')                 | FBB-HKS.SDQ.HSQ.<br>HPC                  | Significant improvement was shown by the neurofeedback group, which resulted in better parent and teacher ratings than the AST group. The effect size was <i>d</i> = 0.60 for the primary outcome measure in the FBB-HKS. Both neurofeedback protocols (SCP and TBR) obtained similar effects   |
| Gevensleben et al. (2009b)*  | 72           | 8–12 (61 M; 11 F)<br>I ( <i>n</i> =24); C ( <i>n</i> =48) | 2 Groups: 1. Neurofeedback (TBR; SCP) ( <i>n</i> =46). 2. AST ( <i>n</i> =26) | 36ses. 6–8 wks/4–6 (50')                 | FBB-HKS                                  | Both groups resulted in significant clinical improvement of the main ADHD symptoms. Neurofeedback group obtained superior improvement compared to AST, with an effect size of <i>d</i> = 0.60. The superiority of FBB-HKS inattention and hyperactivity/impulsivity in neurofeedback group was of 25–30%. These results maintained 6 months follow-up |
| Perreau-Linck et al. (2010)* | 9            | 8–13 (8 M; 1 F)<br>C                                      | 2 Groups: 1. Neurofeedback (SMR; TBR). 2. Placebo                             | 40ses. 7–9 wks/3 (60')                   | CPRS-R:L.CPT-II.BADS-C.CAT.<br>TEA-ch.D2 | Significant improvements were found on the CPRS-R and CPT-II on both groups. Neurofeedback showed inhibition improvement and superiority effects. No effect sizes were reported   |

Table 2 (continued)

| Author/s (year)             | Participants |                   | Design                                 | Total sessions/wks<br>(duration/session) | Evaluation instruments          | Neurofeedback results  |
|-----------------------------|--------------|-------------------|--|--|---------------------------------|--|
|                             | <i>n</i>     | Age (sex)         |  |  |                                 |  |
| Bakhtshayesh et al. (2010)* | 35           | 6–14 (26 M; 91 F) | –                                      | 30ses                                    | –                               | Neurofeedback resulted in a clinically effective treatment in comparison to placebo. Improvement in ADHD symptoms was found in 55.6% of cases  |
| Gevensleben et al. (2010a)* | 94           | 8–12 (77 M; 17 F) | I ( <i>n</i> = 28); C ( <i>n</i> = 66) | 36ses. 6–8 wks/4–6 (50')                 | FBB-HKS, FBB-SSV, SDQ, HSQ, HPC | Neurofeedback group obtained better results than AST group, showing a significant group effect in the primary outcome measure ( $F(1,58) = 10.10$ , $p < 0.005$ ). A medium effect size of $d = 0.71$ was found 6 months follow-up demonstrating that neurofeedback is a clinically efficacious module |
| Gevensleben et al. (2010b)* | 94           | 8–12 (75 M; 19 F) | –                                      | 36ses. 6–8 wks/4 (50')                   | FBB-HKS, FBB-SSV, SDQ, HSQ, HPC | Neurofeedback group obtained higher improvements in ADHD core and associated symptoms, in FBB-HKS with an effect size of $d = 0.60$ , maintained 6 months follow-up, demonstrating that neurofeedback is a clinically efficacious module   |

**Table 2** (continued)

| Author/s (year)           | Participants |   | Design   | Total sessions/wks<br>(duration/session) | Evaluation instruments  | Neurofeedback results   |
|---------------------------|--------------|---|--|--|-------------------------|---|
|                           | <i>n</i>     | Age (sex)   |  |  |                         |   |
| DeBeus and Kaiser (2011)* | 42           | 7–12 (13 M; 29 F)<br>I ( <i>n</i> = 18); C ( <i>n</i> = 24) | 2 Groups: 1. Neurofeedback (alpha; beta; SMR) ( <i>n</i> = 42).<br>2. Placebo ( <i>n</i> = 42) | 20ses. 10 wks/2 (30')                    | CTRS-R:L. CPRS-R:L. IVA | Neurofeedback showed significant clinical improvement in the main symptoms of ADHD. Neurofeedback group resulted in better scores in CTRS-R ( <i>d</i> = 0.50) and in IVA ( <i>d</i> ≈ 0.60). No treatment effects were reported on CPRS-R  |
| Lansbergen et al. (2011)* | 14           | 8–15 (13 M; 1 F)<br>I ( <i>n</i> = 7); H ( <i>n</i> = 7)    | 2 Groups: 1. Neurofeedback (SMR; TBR). 2. Placebo  | 30ses. 16 wks/2 (45')                    | PSERS. SDQ. CGI         | Significant improvement over time in the neurofeedback group in comparison to placebo, in decreasing inattention ( $F(4,48) = 22.07, p < .001$ ) and hyperactivity/impulsivity ( $F(4,48) = 8.09, p < .001$ ). Maintained 6 months follow-up  |
| Wangler et al. (2011)*    | 94           | 8–12 (77 M; 17 F)<br>I ( <i>n</i> = 28); C ( <i>n</i> = 66) | 2 Groups: 1. Neurofeedback (TBR; SCP) ( <i>n</i> = 59). 2. AST ( <i>n</i> = 35)                | 36ses. 6–8 wks/4–6 (25–30')              | FBB-HKS                 | Significant improvement in the primary symptoms (FBB-HKS) with neurofeedback training, especially SCP training, which 30% of its variance ( $R^2 = .286$ ) could have been explained by the predictors CNV ( $\beta = .409, p < .005$ ) and alpha activity ( $\beta = .262, p < .1$ ) |

Table 2 (continued)

| Author/s (year)              | Participants |                   | Design         | Total sessions/wks<br>(duration/session)  | Evaluation instruments                              | Neurofeedback results   |
|------------------------------|--------------|-------------------|----------------|---|---|---|
|                              | <i>n</i>     | Age (sex)         |                |   |   |   |
| Steiner et al. (2011)*       | 41           | 12 (21 M; 20 F)   | –              | 23ses. 16 wks/2 (45')   | CRS-R, BRIEF, BASC-2, IVA-CPT                       | Significant improvement comparing pre-post neurofeedback training in CRS-R and BASC, with an effect size of $p < .05$ . In the SCF module this effect size $p < .05$ was also maintained in CRS-R, BASC and BRIEF               |
| Bakhtshayesh et al. (2011)*  | 35           | 6–14 (26 M; 9 F)  | I ( $n = 29$ ) | 2 Groups: 1. Neurofeedback (TBR) ( $n = 13$ ). 2. SCF ( $n = 13$ ). 3. Waiting list ( $n = 15$ )<br><br>2 Groups: 1. Neurofeedback (TBR) ( $n = 18$ ). 2. EMG-BF (muscular relaxation) ( $n = 17$ ) | FBB-HKS, CPT, BP, D2, FBB-SSV, SDQ, HSQ, HPC        | Neurofeedback training resulted in higher significant clinical improvement in ADHD core symptoms. Parents reported better scores in neurofeedback group compared to EMG-BF ( $d = -0.94$ )                                      |
| Duric et al. (2012)*         | 91           | 6–18 (72 M; 19 F) | –              | 30ses. 3/wks (40')  | CBCL  | Significant changes were informed by parents in all scales within the three groups ( $p < .001$ ). No significant changes were reported between groups  |
| Liechti et al. (2012)*       | 13           | 8–13 (11 M; 2 F)  | C              | 36ses. 9–12 wks/2 (60')   | FBB-HKS, CPRS, SDQ, BRIEF, CTRS, CBCL, HAWIK-IV, D2 | Neurofeedback groups showed significant improvement in ADHD symptoms reported by teachers ( $F(5,8) = 4.009$ , $p = .041$ ) with medium effect sizes and parents ( $F(9,4) = 9.056$ , $p = .024$ ) with medium to large effects |
| Russell-Chapin et al. (2013) | 12           | 9–15 (11 M; 1 F)  | –              | 40ses. 13 wks (20')   | TOVA  | Significant improvement between the first and last session using neurofeedback ( $t(5) = -1.83$ , $p = .05$ )   |



**Table 2** (continued)

| Author/s (year)                   | Participants |                   | Design  | Total sessions/wks<br>(duration/session)  | Evaluation instruments    | Neurofeedback results                           |   |
|-----------------------------------|--------------|-------------------|---|---|---------------------------|---|---|
|                                   | <i>n</i>     | Age (sex)         |   |   |                           |   |   |
| Arnold et al. (2013)*             | 39           | 6–12 (31 M; 8 F)  | I ( <i>n</i> = 13); C ( <i>n</i> = 26)                    | 2 Groups: 1. Neurofeedback (TBR; SMR) ( <i>n</i> = 26). 2. Placebo ( <i>n</i> = 13)             | 30ses.10–15 wks/2–3 (45') | SNAP;CRS-R.BRIEF. IRS.CGI.WIAT-II. WASI         | Both groups improved. No significant differences between treatments were obtained   |
| Kerson (2013)*                    | 180          | 7–10              | –   | 2 Groups: 1. Neurofeedback (TBR) ( <i>n</i> = 108). 2. Placebo ( <i>n</i> = 72)                 | 38ses.13 wks/3            | ChIPS.C-3.IRS.CSHQ. CGI.WASI-II.WIAT-II.IVA.CPT | RCT proposal. Includes training protocol  |
| van Dongen-Boomsma et al. (2013)* | 41           | 8–15 (34 M; 7 F)  | I ( <i>n</i> = 9); H ( <i>n</i> = 2); C ( <i>n</i> = 30)  | 2 Groups: 1. Neurofeedback (SMR; TBR) ( <i>n</i> = 22). 2. Placebo ( <i>n</i> = 19)             | 30ses.12 wks/2 (20')      | ADHD-RS.CGI.CGAS. SDQ.PSERS                     | Both groups showed significant clinical improvements ( <i>p</i> < .001). No significant effect was found due to group × time interaction ( $F(1, 39) = 0.36, p = .554$ )  |
| Li et al. (2013)*                 | 64           | 7–16 (54 M; 10 F) | I ( <i>n</i> = 42); H ( <i>n</i> = 3); C ( <i>n</i> = 19) | 2 Groups: 1. Neurofeedback (TBR; SMR)+MED (MTF) ( <i>n</i> = 32). 2. MED (MTF) ( <i>n</i> = 32) | 40ses.20 wks/2–5 (25–35') | CPT.RCBQ.ACBC. PIAS.SRC.GAF                     | Combined group including neurofeedback showed significantly ( <i>p</i> < 0.05) better post-treatment outcomes, improving parents and teacher's ratings on hyperactivity/impulsivity and total ADHD. Drug dose decreased in the combined group |

Table 2 (continued)

| Author/s (year)           | Participants |                   | Design  | Total sessions/wks<br>(duration/session) | Evaluation instruments                       | Neurofeedback results   |
|---------------------------|--------------|-------------------|---|--|--|---|
|                           | <i>n</i>     | Age (sex)         |   |  |  |   |
| Meisel et al. (2013)*     | 23           | 7–14 (11 M; 12 F) | I ( <i>n</i> =5); C ( <i>n</i> =18)                   | 40ses.20 wks/2 (35')                     | ADHD-RS,TND-scale,<br>CBCL,WISC-IV,<br>WFIRS | Both groups significantly improved comparing pre-post treatment. No significant differences were found between treatments. Neurofeedback group showed highly significant ( $p < .001$ ) improvements in core symptoms of ADHD rated by mothers, with large effect size ( $d = 1.90$ ). In WFIRS, parents ratings significantly decreased, with a large effect size ( $d = 0.68$ ). Maintained 2–6 months follow-up with medium to large effects |
| Ogrim and Hestad (2013)*  | 29           | 7–16 (18 M; 11 F) | I ( <i>n</i> =7); C ( <i>n</i> =22)                   | 30ses.28–44 wks/2 (45')                  | CRS-R,BRIEF,CPT                              | Significant differences between both groups, showing higher improved outcomes in primary ADHD symptoms rated by parents ( $p = 0.033$ ) and teachers ( $p = 0.015$ ) with large effect sizes, respectively, $d = 1.11$ and $d = 1.12$ in MED group  |
| Vollebregt et al. (2014)* | 41           | 8–15 (34 M; 7 F)  | I ( <i>n</i> =9); H ( <i>n</i> =2); C ( <i>n</i> =30) | 30ses.12 wks/2 (20')                     | SA-DOTS,VSS,WISC-III,RAVLT                   | Both treatment groups showed no significant differences in the measured variables   |

**Table 2** (continued)

| Author/s (year)                | Participants |                  | Design                   | Total sessions/wks<br>(duration/session) | Evaluation instruments                  | Neurofeedback results   |
|--------------------------------|--------------|------------------|--------------------------|--|---|---|
|                                | <i>n</i>     | Age (sex)        |                          |  |   |   |
| Maurizio et al. (2014)*        | 25           | 8–13 (22 M; 3 F) | C                        | 36ses.12 wks/2–3 (60')                   | FBB-HKS.CPRS.SDQ.<br>BRIEF.CTRS         | Significant clinical improvement in primary ADHD symptoms was shown in both groups. Neurofeedback group obtained better scores in the total parental FBB-HKS ( $d=0.52$ ), inattention ( $d=0.72$ ) and hyperactivity/impulsivity ( $d=0.36$ ) with higher medium effect sizes  |
| Gevensleben et al. (2014)*     | 40           | 9–16 (38 M; 2 F) | I ( $n=5$ ); C ( $n=5$ ) | 13–24ses.24 wks/1–8 (50')                | FBB-HKS, ADHD-DSM-IV.FBB-SSV, HPC.YTSS. | Neurofeedback showed significant improvement in inattention ( $d=1.00$ ) and hyperactivity/impulsivity ( $d=0.43$ )   |
| Steiner et al. (2014a, 2014b)* | 102          | 12 (69 M; 33 F)  | –                        | 40ses.20 wks/3 (45')                     | CRS.SKAMP.BRIEF.<br>BOSS.               | Neurofeedback group presented significantly improved outcomes compared to CT and control groups. Improvement was rated by parents in inattention ( $p=.001$ ) and executive functioning ( $p=.001$ ), and teachers, with an effect size of $d=0.25$ in inattention. Neurofeedback group resulted in better engagement behavior in BOSS ratings ( $d=0.25$ ) |

Table 2 (continued)

| Author/s (year)                 | Participants |                   | Design | Total sessions/wks<br>(duration/session) | Evaluation instruments              | Neurofeedback results  |
|---------------------------------|--------------|-------------------|--------|--|-------------------------------------|--|
|                                 | <i>n</i>     | Age (sex)         |        |  |                                     |  |
| Steiner et al. (2014a, 2014b)*  | 102          | 7–11 (69 M; 33 F) | –      | 40ses.20 wks/3 (45')                     | CRS.BRIEF.BOSS                      | Neurofeedback group showed significant improvement in inattention ( $d=0.34$ ), executive functioning ( $d=0.25$ ), hyperactivity/impulsivity ( $d=0.23$ ) and BRIEF subscales ( $d=0.31$ ), maintained 6 months follow-up |
| Holtmann et al. (2014a, 2014b). | 144          | 7–9               | C      | 25ses.12 wks/2–3 (60')                   | FBB-ADHS.CGI.TAP<br>SDQ.CPM.KINDL-R | Neurofeedback group obtained better results in comparison to EMG-BF. No further statistical data were reported   |
| He et al. (2014).               | 94           | –                 | –      | 4ses                                     | WISC.CRS.IVA                        | Both groups showed significant improvement in all measures after treatment ( $p<.01$ , $p<.05$ ). Combined group obtained a higher efficacy rate (91.5%) in comparison with the unique treatment (83.3%)                   |
| Bink et al. (2014)*             | 71           | 12–24 (71 V)      | –      | 37ses.25 wks/2–3 (30')                   | ADHD-RS.YSR.CBCL.<br>D2.WASI-IV     | Significant improvement in outcomes (attention, processing time and motor speed) at post-intervention for both groups with medium to large effect sizes ( $\eta_p^2=0.08–0.54$ , $p<.023$ )                                |

**Table 2** (continued)

| Author/s (year)                   | Participants |                    | Design | Total sessions/wks (duration/session) | Evaluation instruments                      | Neurofeedback results  |
|-----------------------------------|--------------|--------------------|--------|---------------------------------------|---|--|
|                                   | <i>n</i>     | Age (sex)          |        |                                       |   |  |
| Duric et al. (2014)*              | 80           | 6–17 (65 V; 15 M)  | –      | 30ses.11–13 wks/3 (45')               | SRQ   | Significant improvement with effects in attention and hyperactivity ( $p < .001$ ) for all the groups. Neurofeedback showed medium to large effect sizes in inattention ( $d = 0.90$ ), hyperactivity ( $d = 0.57$ ) and school performance ( $d = 0.55$ ) |
| Christiansen et al. (2014)*       | 58           | 7–11 (48 V; 10 M)  | –      | 30ses.12 wks/3 (60')                  | CRS,Qb-test,KITAP, CASSS,PS,KINDL-R, PC,ESF | Clinical improvement in ADHD symptoms in both groups. Both treatments resulted in adequate pre-post effects ( $r^2 = 0.175–0.513$ ). No statistical differences were found between NF and SMR ( $p = .81$ )  |
| van Dongen-Boomsma et al. (2015)* | 41           | 5–7 (34 V; 7 M)    | –      | 25–30 wks/2–5                         | ADHD-RS,CGI,CGAS, PSERS,SDQ                 | Both treatments clinically improved in ADHD symptoms. No significant differences were found between groups   |
| Keith et al. (2015)*              | 95           | 18–56 (59 V; 36 M) | –      | 15ses.1.5 wks/5 (30')                 | TOVA  | Both neurofeedback groups showed significant improvement in EEG measures in comparison to the usual treatment group with medium to large effects ( $d = 0.53–0.93$ )   |
| Bink et al. (2015)*               | 71           | 12–24              | –      | 37ses.25 wks/2 (30')                  | ADHD-RS,CBCL,YSR                            | Behavioral problems were significantly improved similarly in both groups with medium to large effect sizes ( $r^2 = 0.08–0.31$ , $p < .05$ )   |

Table 2 (continued)

| Author/s (year)              | Participants |   | Design   | Total sessions/wks<br>(duration/session) | Evaluation instruments  | Neurofeedback results   |
|------------------------------|--------------|---|--|--|---|---|
|                              | <i>n</i>     | Age (sex)<br>Subtype  |  |  |   |   |
| Moreno-García et al. (2015)* | 57           | 7–14 (44 V; 13 M)<br>I ( <i>n</i> = 27); H ( <i>n</i> = 10; C<br>( <i>n</i> = 20) | 3 Groups: 1. Neurofeedback (TBR) ( <i>n</i> = 19), 2. MED (MTF) ( <i>n</i> = 19), 3. BT ( <i>n</i> = 19)   | 30ses. 20 wks/4 (24')                    | IVA   | Significant improvement in all groups, in auditory attention ( $p = .017$ ), global attention ( $p = .002$ ) and visual attention ( $p = .028$ ). Not statistical differences were found between groups   |
| Janssen et al. (2016)*       | 103          | 7–13  | 3 Groups: 1. Neurofeedback (TBR) ( <i>n</i> = 38), 2. MED (MTF) ( <i>n</i> = 31), 3. PA ( <i>n</i> = 34)   | 30ses. 10 wks/3 (45')                    | –   | Significant improved response inhibition with medication ( $p < .001$ ) in comparison to neurofeedback ( $p = .240$ ) and physical activity ( $p = .425$ )  |
| Hasslinger et al. (2016)     | 200          | 9–17  | 4 Groups: 1. Neurofeedback (SCP) ( <i>n</i> = 50), 2. Neurofeedback (LZS) ( <i>n</i> = 50), 3. W/Mt ( <i>n</i> = 50), 4. Waiting list ( <i>n</i> = 50) | 25ses. 5 wks/5 (40')                     | CRS.CPT-II, WISC-IV, WASI-IV, BRIEF, KIDSCREEN-27, CPT, SPSQ                    | RCT proposal. Includes training protocol  |
| Greladé et al. (2016)*       | 103          | 7–13 (85 V; 27 M)   | 3 Groups: 1. Neurofeedback (TBR) ( <i>n</i> = 38), 2. MED (MTF) ( <i>n</i> = 31), 3. PA ( <i>n</i> = 34)   | 19–30ses. 10–12 wks/3 (45')              | DBDRS, SDQ, SWAN  | The three treatments showed improved outcomes. Parent's ratings, in the three groups, showed a significant decrease in hyperactivity/impulsivity in SDQ and SWAN ( $\eta_p^2 = 0.21–0.22$ , $p \leq .001$ ). Inattention improved in MED group compared to neurofeedback or PA (respectively, $\eta_p^2 = 0.13$ , $p \leq .001$ and $\eta_p^2 = 0.14–0.29$ , $p < .001$ ) |
| Blume et al. (2017)          | 90           | 6–10  | 3 Groups: 1. Neurofeedback (VR) ( <i>n</i> = 30), 2. Neurofeedback (n = 30), 3. EMG-BF (VR) ( <i>n</i> = 30)   | 15ses. (60–70')                          | CFT, CRS, SDQ, KINDL-R, SCS-K-D, BRIEF, FERT, WISC-IV, VFT, CPT, LVD-M, SLRT-II | RCT proposal. Includes training protocol  |

**Table 2** (continued)

| Author/s (year)           | Participants |                   | Design  | Total sessions/wks (duration/session) | Evaluation instruments                 | Neurofeedback results  |
|---------------------------|--------------|-------------------|---|---------------------------------------|--|--|
|                           | <i>n</i>     | Age (sex)         |   |                                       |  |  |
| Mohagheghi et al. (2017)* | 54           | 7–10              | C   | 40ses/3 (45')                         | CPRS,K-SADS-PL, ADHD-RS,CPRS-R, CPT-II | Both neurofeedback groups showed significant improvement in ADHD total scores ( $p < .001$ ), inattention ( $p < .001$ ), hyperactivity ( $p < .001$ ) and omission errors ( $p < .001$ ), maintained 2 months follow-up                                       |
| Lee and Jung (2017)*      | 36           | 6–12 (28 M; 9 F)  | I ( $n = 15$ ); H ( $n = 5$ ); C ( $n = 16$ ) | 20ses.10 wks/2 (60')                  | ADS,ARS,K-WISC-III, ADHD-RS            | Combined group obtained significantly ( $p < .01$ ) higher improved parent ADHD ratings with an effect size of $d = 0.98$  |
| Strehl et al. (2017)*     | 144          | 7–9 (119 M; 25 F) | C   | 25ses.12 wks/2–3                      | ADHD-RS,CGI,SDQ, IQ,KIND-R             | Both groups resulted in significant decrease of ADHD core symptoms. Neurofeedback group obtained better outcomes compared to EMG-BF ( $p = .02$ ) with an effect size of $d = 0.57$  |
| Geladé et al. (2017)*     | 103          | 7–13 (85 M; 27 F) | –   | 30ses.10–12 wks/3 (45')               | DBDRS,SDQ,SWAN                         | Combined group improved significantly in outcomes, impulsivity, inhibition and attention ( $\eta_p^2 = 0.09–0.18$ , $p < .008$ ), in comparison to MED and PA. Working memory showed significant improvements in all groups ( $\eta_p^2 = 0.17$ , $p < .001$ ) |

Table 2 (continued)

| Author/s (year)        | Participants |                  | Design                    | Total sessions/wks<br>(duration/session)        | Evaluation instruments              | Neurofeedback results  |
|------------------------|--------------|------------------|---------------------------|---|-------------------------------------|--|
|                        | <i>n</i>     | Age (sex)        |                           |   |                                     |  |
| Janssen et al. (2017)* | 38           | 7–13 (29 M; 9 F) | –                         | 29 ses. 10–12 wks/3 (45')<br>(duration/session) | DBDRS, SDQ, SWAN                    | Significant improvement in ADHD scores ( $p < .001$ ) using neurofeedback. No correlates between these behavioral measures and the EEG individual learning curves were found   |
| Alegria et al. (2017)* | 31           | 12–17 (31 M)     | I ( $n=4$ ); C ( $n=27$ ) | 14 ses. 2 wks/2 (60–65')                        | ADHD-RS, CPRS-R, WREMB-R, CIS, MARS | Pre-post treatment with neurofeedback resulted in decreased ADHD symptoms within groups and were maintained 11 months follow-up. Improvements in outcomes were decreased primary ADHD symptoms (inattention: $F(1,2) = 19.85$ , $p < .0001$ , $d = 0.79$ ; hyperactivity/impulsivity: $F(1,29) = 12.33$ , $p < .001$ , $d = 0.49$ ; total ADHD score: $F(1,29) = 20.41$ , $p < .001$ , $d = 0.69$ ) and secondary outcomes ( $F(1,29) = 18.25$ , $p < .001$ , $d = 0.73$ ) |



**Table 2** (continued)

| Author/s (year)          | Participants |                   | Design   | Total sessions/wks<br>(duration/session) | Evaluation instruments  | Neurofeedback results   |
|--------------------------|--------------|-------------------|--|--|---|---|
|                          | <i>n</i>     | Age (sex)         |  |  |   |   |
| Johnstone et al. (2017)* | 8            | 8–13 (64 M; 21 F) | Subtype –<br>2 Groups: 1. WM+IQ+neurofeedback (delta; alpha; TBR) ( <i>n</i> = 44).<br>2. Waiting list ( <i>n</i> = 41)  | 25ses.6–8 wks/3–4 (20')                  | ADHD-RS,CRS,CBCL, WIAT-II                                     | Neurofeedback group showed a clinical significant improvement in main ADHD symptoms compared to the waiting list group. Neurofeedback resulted in better ratings in hyperactivity/impulsivity ( $F(1,80) = 9.571, p = .003, \eta_p^2 = 0.11$ ), inattention ( $F(1,80) = 5.375, p = .023, \eta_p^2 = 0.07$ ), and executive functions ( $F(1,80) = 12.122, p = .001, \eta_p^2 = 0.14$ ) |
| Duric et al. (2017)      | 81           | 6–18 (72 M; 9 F)  | –<br>3 Groups: 1. Neurofeedback (SMR; TBR; EMG) ( <i>n</i> = 24).<br>2. Neurofeedback (SMR; TBR; EMG)+MED (MTF) ( <i>n</i> = 29).<br>3. MED (MTF) ( <i>n</i> = 28) | 30ses./3                                 | ECBI,SRQ  | Significant improvement was observed within each treatment group ( $p = .01$ ). Parent's and teacher's ratings in the three treatment groups showed significant improvement in inattention, obtaining the combined group better scores (respectively, $p = .01$ and $p = .02$ ). Clinical effects were maintained 6 months follow-up  |
| Döpfner et al. (2017)*   | 521          | 6–11              | –<br>7 Groups: 1. PA+MED. 2. TASH. 3. Waiting list. 4. MED+Counseling. 5. MED+BT. 6. MED+Neurofeedback (SCP). 7. BT  | 25ses. (60')                             | DCL-ADHS,DCL-SSV, CGI,FBB-ADHS, FBB-SSV,CBCL, WFIRS-P,SRs,CPT | RCT proposal. Includes training protocol  |

Table 2 (continued)

| Author/s (year)              | Participants |                   | Design   | Total sessions/wks<br>(duration/session) | Evaluation instruments                    | Neurofeedback results   |
|------------------------------|--------------|-------------------|--|--|---|---|
|                              | <i>n</i>     | Age (sex)         |  |  |   |   |
| Geladé et al. (2018)*        | 92           | 7–13 (70 V; 22 M) | –  | 30ses.10–12 wks/3 (45')                  | SDQ,SWAN,SDSC                             | No significant group differences were found in ADHD measures ( $p = .058-.997$ ), except for higher improved inhibition in MED group compared to neurofeedback and PA ( $p = .040$ ). At 6 months follow-up, this superiority became smaller or non-significant |
| Minder et al. (2018)*        | 77           | 8–15 (50 V; 27 M) | –  | 10–14 wks/1–6 (45–60')                   | CRS,BRIEF,BOSS                            | Both groups showed significant clinical improvements in ADHD symptoms. Parent's ratings presented larger effect size effects ( $\eta_p^2 = .32$ ) than teacher's ratings ( $\eta_p^2 = .10$ )   |
| Moreno-García et al. (2019)* | 57           | 7–14 (44 V; 13 M) | I ( $n = 27$ ); H ( $n = 10$ ); C ( $n = 20$ ) | 40ses.20 wks/4 (24')                     | IVA,ADHD-RS,ADDES                         | Both groups resulted in significant improvement on overall measures, with effect sizes between $d = 0.47-1.03$ . Neurofeedback showed larger average global effect size in IVA/CPT ( $d = 0.80$ )   |
| Rubia et al. (2019)*         | 31           | 12–17 (31 V)      | I ( $n = 4$ ); C ( $n = 27$ )                  | 11ses.2 wks/4 (60–90')                   | ADHD-RS,CPRS                              | Both groups showed significant clinical improvement in ADHD symptoms. Ratings in all measures were improved showing medium to large effect sizes ( $d = 0.43-1.08$ )  |
| Bioulac et al. (2019)*       | 179          | 7–13              | –  | 36ses.9 wks/4 (<30')                     | ADHD-RS,BRIEF,SDQ,CGI,PAERS,SSRS,SDSC,CPT | RCT proposal. Includes training protocol  |

**Table 2** (continued)

| Author/s (year)                           | Participants |                    | Design                         | Total sessions/wks<br>(duration/session)     | Evaluation instruments                                | Neurofeedback results   |
|---|--------------|--------------------|--------------------------------|--|---|---|
|   | <i>n</i>     | Age (sex)          |                                |  |   |   |
| Dobrakowski and Lebecka (2020)*           | 48           | 6–12 (37 V; 11 M)  | –                              | 10–12ses.10 wks/1 (45'<br>(duration/session) | n-back Test.MOXO-test                                 | Neurofeedback group resulted in a significant improvement in working memory ( $p < .001$ ) with a large effect size ( $d = 1.22$ ) in comparison to the control group   |
| Purper-Ouakil et al. (2021)               | 178          | 7–13               | –                              | 36ses.9 wks/4 (<30')                         | ADHD-RS,BRIEF, SDQ,CGI,PAERS, SSRS,SDSC,CPT-3,CHIP-CE | Both groups showed significant pre-post clinical improvements in primary ADHD symptoms and secondary outcomes. Neurofeedback showed significant better scores in ADHD-RS-P hyperactivity/impulsivity ( $p = .03$ ) and SDQ hyperactivity ( $p = .04$ ). In the intermediate and final session, neurofeedback's effects increased in comparison to MED group which maintained stable |
| Neurofeedback Collaborative Group (2021)* | 144          | 7–10 (111 V; 31 M) | I ( $n = 51$ ); C ( $n = 91$ ) | 38ses.14 wks (25')                           | CRS-R<br>CGI<br>FAC                                   | Both groups showed significant improvement ( $p < .001$ , $d = 1.5$ ) in parent's and teacher's ratings for inattention, maintained 13 months follow up. Neurofeedback group required significantly less medication in follow-up ( $p = .012$ )   |

Table 2 (continued)

| Author/s (year)             | Participants |                      | Design  | Total sessions/wks<br>(duration/session) | Evaluation instruments | Neurofeedback results   |
|-----------------------------|--------------|----------------------|---|--|------------------------|---|
|                             | <i>n</i>     | Age (sex)<br>Subtype |   |  |                        |   |
| Aggensteiner et al. (2021)* | 103          | 7–9<br>C             | 2 Groups: 1. Neurofeedback (SCP) ( <i>n</i> = 50). 2. EMG-BF ( <i>n</i> = 53) | 25ses.12 wks/2–3 (60')                   | FBB-HKS,CPT            | Both groups showed significant improvements in all scales ( $p = .05$ ). Neurofeedback group resulted in higher global and inattention parent's rates ( $F(1,65) \geq 5.00$ , $p = .03$ , $\eta_p^2 \geq .07$ ) |

Design, participants and significant results

Publications included in the database search are marked with an \* and those included in the complementary search are marked .

AFM amphetamine; C combined; D-AFM dextroamphetamine; H hyperactivity/impulsivity; I inattention; F female; MTF methylphenidate; Wks weeks; Ses sessions; TBR theta/beta ratio; M male

Bakhshayesh et al. (2010, 2011), Gevensleben et al. (2009a, 2009b), Johnstone et al. (2017), Lee and Jung (2017), Strehl et al. (2017), Van Dongen-Boomsma et al. (2013), Wangler et al. (2011), and Zhonggui et al. (2005) showed that neurofeedback was effective to a significant degree 73.3% of the cases. In the study by Maurizio et al. (2014), these improvements had a medium effect size ( $d = .52$ ) in primary ADHD symptoms. In the publication by Liechti et al. (2012), the behavioral improvements found in children were significant, with medium-large effects, as measured by both parents ( $p = .024$ ) and teachers ( $p = .041$ ). Cho et al. (2004) observed a significant increase ( $p < .01$ ) in selective attention, better information management and less impulsivity. Gevensleben et al. (2014) mentioned that effects were better for inattention ( $d = 1$ ) than for hyperactivity/impulsivity ( $d = .43$ ). The article by Beauregard and Lévesque (2006) and Lévesque et al. (2006) included an experimental (neurofeedback) and control groups. Neurofeedback resulted in brain activity changes normalizing selective attention and response inhibition in children with ADHD compared to the control group.

When improvement in core ADHD measurements was compared to other treatments, Bink et al. (2014) found medium ( $d = .54$ ) improvement in attention and psychomotor speed in the group that received neurofeedback compared to the control group. Gevensleben et al. (2010a, 2010b), found an effect of neurofeedback of  $d = .60$  compared to cognitive training. Other studies by DeBeus and Kaiser (2011), Keith et al. (2015) and Steiner et al. (2011), comparing neurofeedback with control groups and placebo, found improvement in inattention, with a medium effect size ( $d \geq .50$ ). When comparing neurofeedback to cognitive training, Cho et al. (2002) also showed that the difference was significant ( $p < .05$ ). Moreno-García et al. (2015) found improved scores in auditory and visual attention in both the neurofeedback group and the groups that received medication and behavioral therapy, although without statistically significant differences between groups. Steiner et al. (2014a, 2014b) found significant improvements in ADHD symptoms in school children who received neurofeedback in a school setting as compared to cognitive and control training with a moderate effect size ( $d = .43$ ). Steiner et al. (2014a, 2014b) compared the dose of methylphenidate participants were prescribed before and after intervention and recorded significant increases both in children who received cognitive training and in the control group (7.05 mg and 8.54 mg, respectively,  $p < .05$ ), while the increase in dose was minimal in the neurofeedback group (0.29 mg,  $p = .47$ ). The Neurofeedback Collaborative group study also found a much smaller increase in dose of stimulant medication in the neurofeedback group at follow-up, as compared to the sham control group. Both groups showed significant gains, which underscores the

**Table 3** List of instruments, evaluation techniques used and treatments administered in the studies reviewed

| Abbreviation | Definition  |
|--------------|---|
| ACBC         | Achenbach Child Behavior Checklist  |
| ACC          | Anterior Cingulate Cortex   |
| ADDES        | Attention Deficit Disorder Evaluation Scale   |
| ADHD-RS      | Attention Deficit and Hyperactivity Disorder Rating Scale   |
| ADS          | ADHD Diagnostic System  |
| AFM          | Amphetamine   |
| ARS          | ADHD Rating Scale for Parents   |
| AST          | Attention Skills Training   |
| BADS-C       | Behavior Assessment of Dysexecutive Syndrome—Children   |
| BASC-2       | Behavior Assessment System for Children—Second Edition  |
| BF           | Biofeedback   |
| BOSS         | Blinded Classroom Observation   |
| BP           | BP Attention Test (Basisdiagnostik Umschriebener Entwicklungsstörungen im Grundschulalter)            |
| BRIEF        | Brief Rating Inventory of Executive Functioning   |
| BT           | Behavior Training   |
| CAP          | Child Attention Profile   |
| CASSS        | Child and Adolescent Social Support Scale   |
| CAT          | Children's Apperception Test (Brown-Peterson)   |
| CBCL         | Child Behavior Checklist (Barkley)  |
| CCT          | Children's Checking Task  |
| CFT          | Culture Fair Intelligence Test  |
| CGAS         | Children's Global Assessment Scale  |
| CGI          | Clinical Global Impression  |
| CHIP-CE      | Child Report Form of the Child Health and Illness Profile-Child Edition                               |
| ChIPS        | Children's Interview for Psychiatric Syndromes  |
| CIS          | Columbia Impairment Scale-Parent Version  |
| CPM          | Raven's Colored Progressive Matrices  |
| CPRS-R:L     | Conners Parent Rating Scale—Revised, Long Version   |
| CPT          | Continuous Performance Task   |
| CRS-R        | Conners' Rating Scales—Revised  |
| CSHQ         | Children's Sleep Habits Questionnaire   |
| C-SSRS       | Columbia Suicide Severity Rating Scale  |
| CT           | Cognitive Training  |
| CTRS-R:L     | Conners Teacher Rating Scale—Revised, Long Version  |
| D2           | D2 Attention Test (Aufmerksamkeits-Belastungs-Test)   |
| D-AFM        | Dextroamphetamine   |
| DBDRS        | Disruptive Behaviour Disorder Rating Scale  |
| DCL-ADHS     | Diagnose-Checkliste Aufmerksamkeitsdefizit-/Hyperaktivitätsstörungen aus dem Diagnostik-System DISYPS |
| DCL-SSV      | Diagnose-Checkliste Störungen des Sozialverhaltens aus dem Diagnostik-System DISYPS                   |
| ECBI         | Eyberg Child Behavior Inventory   |
| EMG          | Electromyography  |
| ESF          | Eltern-Stress-Fragebogen  |
| FAC          | Functional Assessment Checklist   |
| FBB-ADHS     | Fremdbeurteilungsbogen für Aufmerksamkeitsdefizit-/Hyperaktivitätsstörungen                           |
| FBB-HKS      | Fremdbeurteilungsbogen für Hyperkinetische Störungen  |
| FBB-SSV      | Fremdbeurteilungsbogen für Störungen des Sozialverhaltens   |
| FERT         | Fragebogen zur Erfassung relevanter Therapiebedigungen  |
| fMRI         | functional Magnetic Resonance Imaging   |
| GAF          | Global Assessment of Functioning Scale  |
| HAWIK-III    | Hamburg-Wechsler-Intelligenztest für Kinder—Dritte Auflage  |

**Table 3** (continued)

| Abbreviation | Definition  |
|--------------|---|
| HPC          | Homework Problem Checklist  |
| HSQ          | Humor Styles Questionnaire  |
| IOWA-Conners | IOWA-Conners Behavior Rating Scale  |
| IQ           | Intelligence Quotient   |
| IRS          | Impairment Rating Scale   |
| IVA          | Integrated Visual Auditory Continuous Performance Test  |
| K-BIT        | Kaufman Brief Intelligence Test   |
| KIDSCREEN-27 | Erfassung der Gesundheitsbezogenen Lebensqualität von Kindern und Jugendlichen (Kürzere Version des KIDSCREEN-52) |
| KINDL-R      | Revidierter Fragebogen für Kinder und Jugendliche zur Erfassung der Gesundheitsbezogenen Lebensqualität           |
| KITAP        | Children's Test-Battery of Attention Assessment   |
| K-SADS-PL    | Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime version           |
| K-WISC-III   | Korean-Wechsler Intelligence Scale for Children-III   |
| IPHG         | left Parahippocampal Gyrus  |
| LVD          | Lernverlaufdiagnostik-Mathematik  |
| LZS          | Live Z-Score  |
| MARS         | Maudsley Attention and Response Suppression Task Battery  |
| MED          | Medication Treatment  |
| MOXO-Test    | Computer-based MOXO-d-CPT Test2   |
| MTF          | Methylphenidate   |
| NFT          | Neurofeedback Treatment   |
| ODD-Scale    | Oppositional Defiant Disorder Scale   |
| PA           | Physical Activity   |
| PAERS        | Pediatric Adverse Event Rating Scale  |
| PAL-T        | Paired Associate Learning Task  |
| PC           | Perceived Criticism Scale   |
| PIAS         | Peer Interactions Assessment Scale  |
| PS           | Parenting Scale   |
| PSERS        | Pittsburgh Side Effects Rating Scale  |
| Qb-Test      | Combined-CPT  |
| RAVLT        | Rey Auditory-Verbal Learning Test   |
| RCBQ         | Rutter Children's Behavior Questionnaire  |
| RCQ          | Response Control Quotient   |
| rIFC         | right Inferior Frontal Cortex   |
| rIFG         | right Inferior Prefrontal Cortex  |
| SA-DOTS      | Sustained Attention Dots Task   |
| SCF          | Standard Computer Format  |
| SCP          | Slow Cortical Potentials  |
| SCS-K-D      | Selbstkontroll-Kapazität  |
| SDQ          | Strengths and Differences Questionnaire   |
| SDSC         | Sleep Disturbance Scale   |
| SKAMP        | Swanson, Kotkin, Agler, M-Flynn, and Pelham Scale   |
| SLRT-II      | Lese-und-Rechtschreibtest   |
| SMR          | Sensorimotor-Rhythm   |
| SNAP         | Swanson, Nolan, and Pelham (SNAP) Rating Scales (version of the DSM criteria by Swanson)                          |
| SPSQ         | Swedish Parenthood Stress Questionnaire   |
| SRC          | School Report Card  |
| SRQ          | Self-Regulation Questionnaire   |
| SRS          | Social Responsiveness Scale   |
| SWAN         | Strengths and Weaknesses of ADHD Symptoms and Normal Behavior   |

**Table 3** (continued)

| Abbreviation | Definition  |
|--------------|---|
| TAP          | Testbatterie-Aufmerksamkeitsprüfung                   |
| TASH         | Telephone-Assisted Self-Help                          |
| TBR          | Theta/Beta Ratio                                      |
| TEA-ch       | Test of Everyday Attention for Children               |
| TOVA         | Test of Variables of Attention                        |
| VFT          | Verbal Fluency Task                                   |
| VR           | Virtual Reality                                       |
| VSS          | Visuospatial Sequencing                               |
| WASI         | Wechsler Abbreviated Scale of Intelligence            |
| WFIRS        | Weiss Functional Impairment Rating Scale              |
| WIAT-II      | Wechsler Individual Achievement Test—Second Edition   |
| WISC-IV      | Wechsler Intelligence Scale for Children              |
| WMt          | Working Memory Training                               |
| WREMB-R      | Weekly Rating of Evening and Morning Behavior-Revised |
| YSR          | Youth Self-Report                                     |
| YTSS         | Yale Tourette Symptom Scale                           |

role of non-specific effects. The study outlined by Bioulac et al. (2019) and developed by Purper-Ouakil et al. (2021), showed significant improvement in both groups in ADHD symptoms, as well as in secondary outcomes.

With regard to the reduction in core ADHD symptoms when combined with other treatments, the study by Christiansen et al. (2014) found similar results in the neurofeedback and behavioral therapy groups, and Duric et al. (2017) found the most significant effects with combined neurofeedback and methylphenidate. Li et al. (2013) found that this combined treatment resulted in more significant improvements (maintained after 6 months) than with medication alone with respect to ADHD symptoms ( $p < .05$ ), social functioning ( $p < .001$ ) and smaller increase in methylphenidate dose ( $p < .05$ ).

Effects achieved by neurofeedback on improved ADHD symptoms were maintained for 2–24 months. In the study by Mohagheghi et al. (2017). These effects appeared after 2 months and in the studies by Christiansen et al. (2014), Duric et al. (2017), Lansbergen et al. (2011), Leins et al. (2007), Li et al. (2013) and Meisel et al. (2013) the improvement in ADHD symptoms was maintained up to 6 months. These benefits were maintained for a period of over 6 months in the results reported by Gani et al. (2008) (6–24 months), Alegria et al. (2017) (11 months), Dobrakowski and Lebecka (2020) (12 months) and Neurofeedback Collaborative Group (2021) (13 months). Gani et al. (2008) included a follow-up evaluation carried out not only 6 months after the last training session, but also, they presented data 2 years after the end of the treatment. This was one of the first long-term RCT study including such a long period of time of follow-up, showing that clinical outcome and self-regulation

skills maintained invariable, and in some cases, presenting improvements.

Referring to the improvement in other noncore ADHD behaviors or measurements, the studies by Linden et al. (1996) and Lubar et al. (1995) recorded a significant 10 point increase in intelligence scores with neurofeedback. Furthermore, among the effects of neurofeedback, Bink et al. (2015) found a reduction in other behavioral problems in the group of usual treatment and in the one combined with neurofeedback. Holtmann et al. (2009) found that the neurofeedback group had better results than cognitive training in behaviors such as opposition and physical aggression and Duric et al. (2014) found that neurofeedback led to significant improvements with large effect sizes in attention ( $d = .90$ ) and hyperactivity ( $d = .57$ ), and medium effect size in school performance ( $d = .55$ ). Gevensleben et al. (2009a, 2009b) also reported a reduction of ADHD symptoms and of other associated problems, such as social adaptation, finding medium effects ( $d = .60$ ) when neurofeedback was compared to cognitive training.

However, findings are not consistent across all studies. There are results that did not demonstrate improvement in ADHD symptoms. The publications by Duric et al. (2012) and van Dongen-Boomsma et al. (2015) did not find any significant difference in primary ADHD symptoms when the neurofeedback group was compared to the other study groups (medication and placebo). Neither did Vollebregt et al. (2014) find any significant differences in core symptoms between the neurofeedback group and placebo group. Heywood and Beale (2003) found that the placebo group was better than neurofeedback, although the effect was small ( $d = .24$ ). Another group of results showed that the

comparison group (placebo, medication with methylphenidate and dextroamphetamine, acupuncture and physical activity) showed better results than neurofeedback in reducing inattention, hyperactivity and/or impulsivity (Arnold et al., 2013; Ogrim & Hestad, 2013; Perreau-Linck et al., 2010). He et al. (2014) found that the combination of acupuncture and neurofeedback had better scores on intelligence and ADHD symptoms, with a total efficacy rate of 91.5% in acupuncture plus neurofeedback and 83.3% in neurofeedback alone. Janssen et al. (2016) recorded improvements in brain function, more specifically, improved response inhibition, with medication ( $p < .001$ ) than with neurofeedback ( $p = .240$ ) and physical activity ( $p = .425$ ). Comparing these three groups, Geladé et al. (2016, 2017, 2018) concluded that methylphenidate was superior to both neurofeedback and physical activity in reducing symptoms in children with ADHD with a medium effect size ( $\approx d = .5$ ). However, in the 6-month postintervention follow-up, Geladé et al. (2018) found no significant difference.

## Discussion

The objective of this study was to review the efficacy of neurofeedback as a treatment for children and adolescents with ADHD by means of a systematic review of RCTs conducted in the last 27 years. For this purpose, the main characteristics of these studies were analyzed in terms of scientific productivity and their geographic and temporal distribution.

The review concluded that there has been an increase in the number of studies with a RCT design, scientific productivity has grown in recent years; and the highest number of publications came from Germany. Insofar as evidence concerning the effectiveness of neurofeedback, it was observed to be effective in over half of the RCTs reviewed, with beneficial effects on intelligence, oppositional behavior, aggression and social and school functioning. However, data were not consistent across the studies concerning the maintenance of these effects.

When the results were analyzed, it was observed that our criterion concerning studies with participants without an ADHD diagnosis or with comorbid disorders/alterations, was the most restrictive, as it led to exclusion of a large number of studies that had previously been selected. Although in publications, such as the review by Lofthouse et al. (2012), studies with participants with comorbid disorders were specified, we did not find any study that excluded publications according to this criterion. In this case, in order to focus on the objective of the study of the effects of neurofeedback on ADHD with no comorbidity, this exclusion criterion was considered necessary.

In this review, most of the studies included are RCTs. These data are contradictory to the findings of Gaviria et al.

(2014), perhaps because, in that study, scientific reviews prevailed, and, it should be taken into account that fewer studies were reviewed by those authors, which could explain the differences with respect to their conclusions and the results reported here.

The data extracted demonstrate the increase in scientific productivity in RCTs, in agreement with Servera and Moreno (2015), who observed a progressive increase in these publications since the nineties. The findings on countries where the scientific productivity was concentrated partly coincides with the results of Gaviria et al. (2014). This study differs because the USA ties with the Netherlands for second place, as opposed to the findings of those authors which position Switzerland as the country where research productivity was high. Of the 67 randomized controlled trials reviewed, 38 (56%) came from Germany, the Netherlands and USA. Norway was in third place with four studies and Switzerland, with three studies, tied for fourth place with Canada, China, Korea and Spain. England, France and Iran contributed two studies each, while Australia, New Zealand, Poland and Sweden all published one RCT.

Evidence on neurofeedback and its beneficial effects is consistent with the findings by Holtmann et al. (2014a, 2014b) and Weber et al. (2020) indicating that neurofeedback significantly improves primary symptoms of ADHD. In this study, the effects were particularly observed in attention and impulsivity and, to a lesser extent, in hyperactivity. Progress in this direction comes from the results found by Weber et al. (2020), which identified in the studies reviewed, various predictors that favored the efficacy of neurofeedback. Among them, they included as possible predictors, the electrophysiological baseline measures of the participants, such as presenting higher activation at baseline, before training sessions. Furthermore, other predictors could be based on the initial training phase, examining the learning ability of the participants by evaluating the performance in training sessions. This could predict future training execution, rather than employing the usual baseline parameters before the first training session. In the recent review by Sampedro Baena et al. (2021), the combination of neurofeedback with other types of intervention, such as behavioral therapy and physical activity, achieved better clinical results.

Nevertheless, as the results show, these effects are not conclusive in all the studies reviewed. Such findings agree with the results extracted in the meta-analysis done by Van Doren et al. (2019). That study demonstrated that the effects are not universal, as neurofeedback did not improve the core symptoms of ADHD, or other associated symptoms, in all the studies reviewed, studies in which the children continued taking medication even during neurofeedback treatment. Some years before that, the review by Willis et al. (2011) also had shown contradictory results on the effects of neurofeedback. The review by Rubia et al.



(2021) also concluded that more systematic studies are necessary to clarify the specific effects of neurofeedback and its clinical implications.

Our findings agree with the study by Holtmann et al. (2014a, 2014b), which concluded that the effects of neurofeedback were maintained in the long term, from 6 to 24 months after treatment. Maintenance of these effects, confirmed in a number of the studies we have reviewed, establishes lasting effects as an added advantage of neurofeedback over other types of treatment such as medicating where effects do not last in the long term. This was also among the conclusions of the meta-analysis by Arns et al. (2009). Furthermore, the review by García-Pimenta et al. (2021), showed that multimodal designs including personalized application of neurofeedback showed better results than its application alone and compared to medication. In addition, the paper by Louthrenoo et al. (2022) concluded that it was also important to include information about executive function outcomes based on neuropsychological evaluation when applying neurofeedback. Finally, the study by Arns et al. (2020) strongly recommend that it should be applied in compliance with the guidelines proposed by organizations specialized in neurofeedback.

The limitations of this study derive mainly from the heterogeneity of the studies reviewed. They differ in methodology, characteristics and inclusion criteria of the participants, mostly obviating the incorporation of the participants to the groups by psychophysiological criteria, an issue that, if carried out, would make possible the administration of specific training protocols according to different endophenotypes. This is a limitation of the works reviewed, which, in addition, differ in training protocols, equipment used, evaluation instruments, measures of efficacy and statistical analyses, thus impeding the extraction of conclusive results concerning the evidence for neurofeedback's efficacy. Nevertheless, the wide period covered by the current analysis is an important addition to the literature. By covering all the RCT of neurofeedback for ADHD conducted across the past 27 years, this review provides an up-to-date panorama of scientific research on the subject. Still pending for future research is an extension of this review to other databases and sources and widening the search criteria to include other relevant studies. Perhaps greater standardization of methods for applying neurofeedback, the management of psychophysiological criteria for the inclusion of participants in the different randomized groups, will facilitate the administration of specific training protocols and, consequently, a wider and more adapted application of its use will generate further RCT evidence that will facilitate meta-analyses that would make it possible to elucidate the specific effects of neurofeedback training in the treatment of ADHD.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest, excluding the above.

**Ethical Approval** This systematic review was performed following the guidelines and protocols PRISMA, PRISMA-P (Page et al., 2021).

**Informed Consent** Not applicable.

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