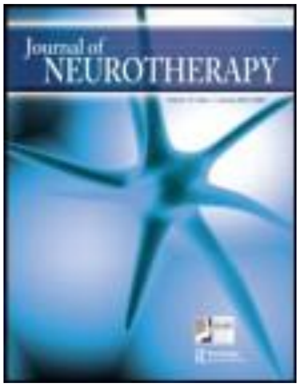

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Does Neurofeedback Help Reduce Attention-Deficit Hyperactivity Disorder?

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SCIENTIFIC FEATURES

Does Neurofeedback Help Reduce Attention-Deficit Hyperactivity Disorder?

Jaclyn M. Williams, BS, MSW

ABSTRACT. *Introduction*: Neurofeedback is an alternative treatment for Attention Deficit Hyperactivity Disorder (ADHD), but its efficacy is unknown. This narrative review examines rigorous studies conducted utilizing neurofeedback as a treatment for ADHD.

Methods: Studies were located by searching the Web of Science and PsycINFO databases with the keywords *ADHD* or *attention deficit hyperactivity disorder* AND *neurofeedback* or *EEG biofeedback* or *electroencephalogram biofeedback*. Located studies were chosen for initial review if they met the following criteria: (a) randomized controlled trial or quasi-experiment, (b) ADHD diagnosis based on *DSM* criteria, (c) published at any time prior to March 2010, (d) English language, and (e) published in a peer-reviewed journal. Participants included children, adolescents, and adults diagnosed with ADHD.

Results: Twelve articles reporting 9 different studies met the eligibility criteria and were included in the review. All 9 studies produced results that indicated significant improvements on either tests scores or behavioral conduct for individuals who were treated with neurofeedback for ADHD. Alternative treatments also demonstrated effectiveness.

Conclusion: Neurofeedback may be an effective treatment for ADHD. Future research is needed with larger sample sizes, comparing the efficacy of neurofeedback with the efficacy of other ADHD treatments and comparing different neurofeedback protocols.

KEYWORDS. ADHD, attention deficit hyperactivity disorder, EEG biofeedback, electroencephalogram biofeedback, narrative review, neurofeedback

INTRODUCTION

Attention-Deficit/Hyperactivity Disorder (ADHD) is an Axis I diagnosis under the Attention-Deficit and Disruptive Behavior disorder category. According to the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev. [*DSM–IV–TR*]; American Psychiatric Association, 2000, pp. 85–93), a person can be diagnosed with

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ADHD if they have six or more symptoms of either inattention or hyperactivity-impulsivity that have lasted for at least half a year.

The symptoms for inattention include (a) not paying attention to details or making careless mistakes, (b) having trouble sustaining when doing tasks or while playing, (c) not appearing to hear when being spoken to directly, (d) not following directions and not finishing tasks, (e) having trouble organizing tasks and activities, (f) avoiding or showing dislike for activities for which sustained mental effort is required, (g) frequently losing materials needed to complete tasks or activities, (h) being easily distracted by outside things, and (i) being forgetful during daily activities.

The symptoms for hyperactivity include (a) fidgeting or squirming; (b) getting up in situations where they are supposed to remain seated, such as in a classroom; (c) running or climbing a lot when they are not supposed to; (d) having trouble playing quietly; (e) consistently appears to be full of energy; and (f) talks a lot. The symptoms for impulsivity include (a) giving answers before the question has been completed, (b) having trouble waiting their turn, and (c) frequently interrupting or intruding on others.

These symptoms have to be inconsistent with the person's developmental level and to cause problems in two or more settings (such as at school or work and home). The problems must be severe enough to cause clinically significant impairment. Some of the symptoms should have been apparent before the person was 7 years old. Also, the symptoms must not be better explained by some other disorder. Most individuals diagnosed with ADHD are diagnosed as children or adolescents.

The most common form of treatment for ADHD is currently medication. "So far, medication (methylphenidate) is the most effective treatment though it has disadvantages and limitations" (Gevensleben, Holl, Albrecht, Vogel, et al., 2009, p. 780). There are concerns about pharmacological treatment for ADHD, particularly side effects and long-term effects (Leins et al., 2007). Also, medication effects may decline over time due to a decrease in participant compliance with medication regimens (Jensen et al., 2007). Neurofeedback (also called EEG biofeedback) is considered "one of the most promising options" (Heinrich, Gevensleben, & Strehl, 2007). There is some debate about the effectiveness of neurofeedback, however. This review is needed to synthesize the current literature on neurofeedback and its effectiveness on persons with ADHD.

Neurofeedback makes use of an electroencephalogram (EEG) machine to analyze the client's brainwaves. "It has now become clear that the primary symptoms of Attention Deficit/Hyperactivity Disorder . . . are really secondary outcomes resulting from an underlying neurological disorder" (Lubar, Swartwood, Swartwood, & O'Donnell, 1995, p. 84). A dysfunction of fronto-striatal systems has been discovered in functional and volumetric brain images of individuals with ADHD that might explain deficits of higher order motor control, arousal, behavioral inhibition, and attention (Fuchs, Birbaumer, Lutzenberger, Gruzeilier, & Kaiser, 2003). "The primary symptoms of ADHD—inattentiveness, impulsiveness, and hyperactivity—are ensured to be the result of pathological neurophysiology and are reflected in specific electrophysiological patterns" (Leins et al., 2007, p. 74). In neurofeedback, "brainwaves of individuals are measured and the amplitudes of brainwaves are shown to the individuals receiving feedback" (Carmody, Radvanski, Wadhwani, Sabo, & Vergara, 2000, p. 7). Neurofeedback allows individuals with ADHD to view their brain activity as shown by an EEG machine. It shows them the difference between what their EEG results are when they are focused on a task and their EEG results when they are distracted. The idea is to teach the client how to recognize the feeling of being focused so that they can have more control over it. To do this, the client "alter[s] the amplitudes of selected brainwaves" (Carmody et al., 2000, p. 7).

Neurofeedback, or EEG biofeedback, involves a client's focus on certain activities in order to manipulate their own brainwaves, but different activities focus on different types of brainwaves. According to Kropotov et al. (2007), neurofeedback protocols were created when it was observed that children with ADHD tend to have a slowing of EEG rhythms. It was observed that theta brainwaves (4–8 Hz) were enhanced and that beta brainwaves (16–20 Hz) were reduced in people with ADHD. Theta waves are often higher when a person is sleepy, whereas beta waves are higher when a person is energized or focused on something. "A conventional neurofeedback protocol for reducing inattention and impulsivity consists of enhancement beta activity and suppressing theta activity" (Kropotov et al., 2007, p. 4; see also Linden, Habib, & Radojevic, 1996; Lubar et al., 1995).

> Several EEG rhythms which reflect maturation and arousal or attention during wakefulness show subtle abnormalities in ADHD. The most common neurophysiological abnormalities in the spontaneous EEG of ADHD subjects are increased slow wave activity (mainly theta) and/or reduced alpha and beta activity in the resting EEG (a relaxed awake state, usually with eyes closed). (Doehnert, Brandeis, Straub, Steinhousen, & Drechsler, 2008, p. 1446)

Training of slow cortical potentials (SCPs) is also a common form of neurofeedback treatment of ADHD. According to Gevensleben, Holl, Albrecht, Vogel, et al. (2009), SCPs are created over the sensorimotor cortex. In treatment, negative SCPs designate increased cortical activation, whereas positive SCPs designate suppressed cortical activation. Theta/beta and SCP training deal with different aspects of cortical regulation which are important for attentive behavior (Gevensleben, Holl, Albrecht, Vogel, et al., 2009).

Newer methods of neurofeedback often come in the form of video games. For example, participants may wear a headset that allows them to control the video game by altering their brainwave patterns. For example, in a game of car racing, a car might move faster if the participant is focusing hard on making the car move. If the participant gets distracted, the car would slow down and the game might make a noise or a vibration to capture the attention of the participant and remind him or her to focus on the game. This intervention is meant to work with individual clients rather than in a group setting.

According to Butnick (2005), neurofeedback has been used for decades in the treatment of ADHD. Some of the earliest work was done by Lubar and Shouse (1977), particularly in the demonstration of the effects of neurofeedback after participants are weaned from medication. Neurofeedback has been received with varying opinions since its inception. Although study reports have been favorable for the intervention, critics note the lack of rigor in studies conducted to date and call for studies with comparison groups and randomization (Gevensleben, Holl, Albrecht, Vogel, et al., 2009). The primary objective of the present article is to complete a narrative review of experimental and quasi-experimental studies of neurofeedback for people with ADHD and to synthesize the results of these studies to assess the effect of neurofeedback on reducing ADHD.

METHOD

Studies were identified through electronic bibliographic databases and manual searches. Databases searched included PsycINFO and ISI Web of Science. The search terms used to guide the database searches included the following: *ADHD* or *attention deficit hyperactivity disorder* AND *neurofeedback* or *EEG biofeedback* or *electroencephalogram biofeedback*. For the ISI Web of Science, the keywords were searched for in the "title" field. For PsycINFO, the keywords were inputted into both the "keyword" and "title" fields.

Located studies were chosen for initial review if they met the following criteria: (a) randomized controlled trial or quasi-experiment, (b) ADHD diagnosis based on *DSM* criteria, (c) published at any time prior to March 2010, (d) English language, and (e) published in a peer-reviewed journal. Using this approach, 3,302 studies were initially located and titles were examined; of those, 69 abstracts were studied. Twenty full text articles were examined further. Twelve articles were retained for the review. Three of the retained articles reported new information pertaining to other studies in the final list. These redundant articles were retained, but data from the same studies were reported together. Of the remaining 9 articles, 4 were experimental and 5 were quasi-experimental studies. These studies are discussed next.

RESULTS

Study Characteristics

The studies reviewed included quasi-experimental designs: Doehnert et al. (2008); Drechsler et al. (2007); Fuchs et al. (2003); Monastra, Monastra, and George (2002); Rossiter (2004); and Rossiter and La Vaque (1995). The studies also included experimental designs involving random assignment to treatment conditions: Beauregard and Levesque (2006); Carmody et al. (2000); Gevensleben, Holl, Albrecht, Schlamp, et al. (2009); Gevensleben, Holl, Albrecht, Vogel, et al., (2009); Levesque, Beauregard, and Mensour (2006); and Linden et al. (1996). Sample sizes ranged from 16 to 100 participants. Three study groupings compared neurofeedback to no treatment: Beauregard and Levesque (2006), Carmody et al. (2000), Levesque et al. (2006), and Linden et al. (1996). Three study groupings compared neurofeedback to stimulant medication: Fuchs et al. (2003), Rossiter (2004), and Rossiter and LaVaque (1995). The final three study groupings compare neurofeedback to alternative treatments: Drechsler et al. (2007) and Doehnert et al. (2008) used cognitive-behavioral group therapy; Monastra et al. (2002) used a combination of stimulant medication, parent counseling, and school consultation—the neurofeedback group had the alternative treatment and neurofeedback; and Gevensleben, Holl, Albrecht, Schlamp, et al. (2009) and Gevensleben, Holl, Albrecht, Vogel, et al. (2009) used attention skills training. An overview of the 12 retained articles is shown in Table 1, including information on each study's intervention, population, design, outcome measures, and results.

Various instruments were used to measure treatment outcomes. Outcome measures of ADHD presented in this review are divided into four categories: laboratory, attention, behavioral, and other measures. Laboratory measures included EEG and event-related potential recordings to measure contingent negative variation (CNV) amplitude, Quantitative Electroencephalographic Scanning Process (QEEG; Monastra et al., 1999), and functional magnetic resonance imaging (fMRI).

Attention measures included Integrated Visual and Auditory Continuous Performance Test (IVA), Test of Variables of Attention (TOVA), Attention Endurance Test (also known as D2), Test for Attention Performance (TAP): Go/NoGo (a subtest of TAP), Alertness (a subtest of TAP), Test of Everyday Attention for Children (Tea-ch): Score! (a subtest of the Tea-ch), Code transmission (a subtest of the Tea-ch), Wechsler Intelligence Scale for Children (WISC): WISC-Revised (German), WISC III, and Digit Span (a subtest of the WISC–R).

Behavioral measures included Child Behavior Checklist, German standardized *DSM–IV* questionnaire for ADHD (FBB-HKS), German Rating Scale for Oppositional Defiant/Conduct Disorders (FBB-SSV), Strength and Difficulties Questionnaire (SDQ), the Home Situations Questionnaire, the Homework Problem Checklist, Behavior Assessment System for Children (BASC), MMPI–2, Personality Inventory for Children, Brown Attention-Deficit Disorder Scales, Conners' Rating Scale: Conners' Parent Rating Scale (CPRS), Conners' Teacher Rating Scale, CPRS–Revised, IOWA-Conners' Behavior Rating Scale, IOWA-Conners' Behavior Rating Scale (German version), Attention Deficit Disorders Evaluation Scale (ADDES Home and School), Behavior Rating Inventory for Executive Function (BRIEF), Teacher's version of the BRIEF, and the Parent SNAP Behavior Rating Scale Index for Inattentive Behaviors.

TABLE 1. Referenced articles.

Authors	Intervention	Study Population	Study Design	Outcome Measures	Results
Rossiter & La Vaque (1995)	Neurofeedback (n = 23) vs. psychostimulants (n = 23)	46 people (ages 8–21) with ADHD	O X O —— O Y O	• Test of Variables of Attention (TOVA) • Behavior Assessment System for Children (BASC) • Personality Inventory for Children • MMPI-2	Both psychostimulants and neurofeedback may be effective treatments for ADHD. However, multiple treatment interferences arose.
Monastra, Monastra, & George (2002)	Clinical care program + Neurofeedback (n = 51) vs. Clinical care program (n = 49)	100 children (ages 6–19) with ADHD	O X O_w O_y O_w —— —— —— O Y O_w O_y O_w	• Attention Deficit Disorders Evaluation Scale (ADDES Home and School) • Test of Variables of Attention (TOVA) • Quantitative Electroencephalographic Scanning Process • Kaufman Brief Intelligence Test (KBIT) • Wechsler Scale (WISC-R or III, WAIS-R)	EEG biofeedback may be an effective treatment for ADHD and may have effects beyond those of stimulant medication, parent counseling, and school consultation.
Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser (2003)	Neurofeedback (n = 22) vs. Methylphenidate (n = 12)	34 German children (ages 8–12) with ADHD	O X O —— O Y O	• Test of Variables of Attention (TOVA) • Attention Endurance Test (d2) • IOWA-Conners Behavior Rating Scale (German) • The Wechsler Intelligence Scale for Children-Revised	These results indicate that both neurofeedback training and methylphenidate may be effective treatments for ADHD.
Rossiter (2004)	Neurofeedback (n = 31) vs. Stimulants (n = 31)	61 (ages 7–55) with ADHD	O X O —— O Y O	• Test of Variables of Attention (TOVA) • Behavior Assessment System for Children (BASC) • Brown Attention-Deficit Disorder Scales	Both psychostimulants and neurofeedback may be effective treatments for ADHD.
Drechsler, Straub, Doehnert,	Neurofeedback (n = 17) vs. CBT group therapy (n = 13)	30 children (ages 9–13) with ADHD	O X O —— O Y O	• German standardized DSM-IV questionnaire for ADHD (FBB-HKS)	Both neurofeedback training and CBT group therapy may be effective

(*Continued*)

TABLE 1 (continued)

Authors	Intervention	Study Population	Study Design	Outcome Measures	Results
Heinrich, Steinhausen, & Brandeis (2007)[b]				• Conners' Parent Rating Scale (CPRS) • Behavior Rating Inventory for Executive Function (BRIEF) • Child Behavior Checklist (CBCL) • Conners' Teacher Rating Scale (CTRS) • Teacher's version of the BRIEF • German WISC III • Alertness [subtest of Test for Attentional Performance (TAP)] • Go/NoGo [subtest of TAP] • Attention Endurance Test (d2) • Score! [subtest from the Test of Everyday Attention for children (Tea-ch)] • Code transmission (Tea-ch) • Trail Making Test	treatments for ADHD. Neurofeedback participants may not be able to translate some skills into daily life.
Doehnert, Brandeis, Straub, Steinhausen, & Drechsler (2008)[b]	Neurofeedback vs. CBT group therapy	26 children (ages 9–12) with ADHD from the Drechsler et al. (2007) study	O X O —— O Y O	• Electroencephalogram (EEG) and event-related potential (ERP) recordings to measure contingent negative variation (CNV) amplitude	The researchers expected to find an improvement in CNV for participants who were in the NFT group, but that was not the case. Researchers note that participants who performed well in the neurofeedback training had less CNV reduction than those who did not.
Linden, Habib, & Radojevic	Neurofeedback vs. No treatment	18 children (ages 5–15) with ADHD 6 children	R O X O	• Composite IQ score on the Kaufman-Brief Intelligence	EEG biofeedback may be useful for reducing

(1996)		also had learning disabilities	R O O	Test (K-BIT) • Parent IOWA Conners behavior rating scale • Parent SNAP behavior rating scale index for inattentive behaviors	inattention symptoms of ADHD.
Carmody, Radvanski, Wadhwani, Sabo, & Vergara (2000)	Neurofeedback (n = 8) vs. No treatment (n = 8)	16 children (ages 8–10): 8 with ADHD (intervention group n = 4; waitlist group n = 4) 8 without ADHD (intervention group n = 4; waitlist group n = 4)	R O X O X O R O O O	• Test of Variables of Attention (TOVA) • Attention Deficit Disorders Evaluation Scale (ADDES)	Results indicate that neurofeedback may be useful for reducing inattention symptoms of ADHD, but the authors recommend more research before any associations are made due to study limitations.
Beauregard & Levesque (2006)[a]	Neurofeedback (n = 15) vs. No treatment (n = 5)	20 children (ages 8–12) with ADHD	R O X O R O O	• Functional magnetic resonance imaging (fMRI) • Digit Span Subtest of the Wechsler Intelligence Scale for Children-Revised (WISC-R) • Integrated Visual and Auditory Continuous Performance Test • Connors Parent Rating Scale-Revised (CPRS-R)	Neurofeedback may be an effective treatment for ADHD.
Levesque, Beauregard, & Mensour (2006)[a]	Neurofeedback (n = 15) vs. No treatment (n = 5)	20 children (ages 8–12) with ADHD	R O X O R O O	• Functional magnetic resonance imaging (fMRI) • Digit Span Subtest of the Wechsler Intelligence Scale for Children-Revised (WISC-R) [attention span] • Integrated Visual and Auditory Continuous Performance Test [visual and auditory attention]	Neurofeedback may be useful in normalizing the functioning of the right anterior cingulated cortex (ACC) in individuals with ADHD. The ACC is important in selective attention (Levesque et al., 2006).

(*Continued*)

TABLE 1 (continued)

Authors	Intervention	Study Population	Study Design	Outcome Measures	Results
				• Connors Parent Rating Scale-Revised (CPRS-R) [parent reports of child's behavioral problems]	
Gevensleben, Holl, Albrecht, Vogel, Schlamp, Kratz, Studer, Rothenberger, Moll, & Heinrich (2009)[c]	Neurofeedback ($n = 59$) vs. Attention Skills Training ($n = 35$)	94 children (ages 8–12) with ADHD	R O X O X O R O Y O Y O	• German ADHD rating scale (FBB-HKS) • German Rating Scale for Oppositional Defiant/Conduct Disorders (FBB-SSV) • Strength and Difficulties Questionnaire • The Home Situations Questionnaire • The Homework Problem Checklist	Both attention skills training and neurofeedback training may be effective treatments for ADHD, but neurofeedback may be more effective than attention skills training.
Gevensleben, Holl, Albrecht, Schlamp, Kratz, Struder, Wangler, Rothenberger, Moll, & Heinrich (2009)[c]	Neurofeedback vs. Attention Skills Training	72 children from the Gevensleben, Holl, Albrecht, Vogel et al. (2009) study	R O X O X O R O Y O Y O	• German ADHD rating scale (FBB-HKS) • German Rating Scale for Oppositional Defiant/Conduct Disorders (FBB-SSV) • Strength and Difficulties Questionnaire • The Home Situations Questionnaire • The Homework Problem Checklist	The analysis indicated that neurofeedback led to a decrease in theta activity and that the reduction was comparable in both SCP and theta/beta blocks, but that neither block was significant on its own. The authors discuss the need for more research on how to adjust neurofeedback training protocols for optimum results.

[a]These articles refer to the same study.
[b]These articles refer to the same study.
[c]These articles refer to the same study.

Other measures included Trail Making Test for Children—indicative of switching costs, Evaluation scales (Froemke Inventory)—questions for parents about the intervention their children received, and the Kaufman Brief Intelligence Test (KBIT).

Study Outcomes

Quasi-Experimental Designs

Rossiter and La Vaque (1995). The Rossiter and La Vaque (1995) study population consisted of a sample of 46 individuals (ages 8–21) diagnosed with ADHD or Undifferentiated Attention Deficit Disorder as described in the *DSM–III–R* (American Psychiatric Association, 1987) by the first author. Two treatment groups of 23 participants were formed based on the types of treatment the participants received. All individuals treated with EEG biofeedback (EEG) who had taken the TOVA were included in the EEG group. The second treatment group consisted of 23 individuals drawn from a pool of 39 people treated with stimulant medication who had taken the TOVA. The participants were drawn to match the EEG group participants based on age. Treatment group assignments were not random. EEG biofeedback and stimulant medication were not the only treatments used for all participants. Some participants were involved in additional interventions such as school behavior modification programs. Parents in both groups received behavior management training with equal frequency, but participants of the medication group were more likely to participate in a school behavior modification program during the course of the intervention because many of these participants were treated during the school year, as opposed to the EEG participants who were primarily treated during the summer vacation. Participants were not involved in individual psychotherapy or family therapy during the time of the intervention.

The EEG biofeedback intervention varied among individual participants. The protocols were based on those developed by Lubar and Lubar (1984) and Othmer and Othmer (1992). The Lubar protocols involve the suppression of activity in the theta range (4–8 Hz) for children fourteen or younger, increasing sensorimotor (SMR) rhythm output (12–15 Hz) or beta (16–20 Hz) output for adults who are 20 or older, and a combination of theta inhibition and SMR or beta enhancement between the ages of 14 and 20. The Othmer protocols enhance SMR (12–15 Hz) or beta (15–18 Hz) output regardless of the participant's age. EEG biofeedback treatment sessions lasted for 45 to 50 minutes three to five times a week with three 10-min segments or two 15-min segments each session. There were 20 sessions administered over a 4- to 7-week period.

Pretreatment measures for both groups included the TOVA and intelligence testing if the participant had no current IQ data. The intelligence testing utilized either the KBIT or the age-appropriate Wechsler Intelligence Scale. Fourteen members of the EEG group were administered the BASC. The other 10 members were evaluated using the MMPI–2 (for participants older than 18) or the Personality Inventory for Children. Five participants in the EEG group and 4 participants in the medication group were taking stimulants at the time of the pretreatment evaluation. These participants stopped taking the medication 2 days before the pretreatment evaluation. The 5 EEG participants remained on the medication throughout the treatment program. These participants stopped taking the medication 2 days before the posttreatment evaluation. The medication group was tested before beginning medication and then after a minimum of 3 days after medication began to determine dosage, the TOVA was administered again. Once the maintenance dose was found, no more outcome measures were taken.

Both groups demonstrated significant improvement on the TOVA scores from pretreatment to posttreatment. The gains achieved by each group were not significantly different from each other. The EEG group also displayed significant improvement on the BASC scales demonstrating a reduction in ADHD symptoms. Behavioral improvement by the BASC reports was corroborated by improvements in TOVA scores. These findings suggest that both EEG biofeedback and stimulant medication may be used to treat ADHD; however, this study was subject to a number of limitations. There was no random assignment into groups, some of the EEG group took stimulant medication during treatment, and many participants in both groups had alternative treatment occurring simultaneously with the assigned treatment.

Monastra et al. (2002). The Monastra et al. (2002) study population consisted of a sample of 100 students (ages 6–19) independently diagnosed with ADHD by a licensed clinical psychologist, using the *DSM–IV* criteria (American Psychiatric Association, 1994). None of the children had been treated for ADHD before the study. Parents completed the Home version of the ADDES and teachers completed the School version of the ADDES. The children were administered the TOVA and participated in a QEEG scanning process. For a child to be included in the study, all of the measures had to be consistent with a diagnosis of ADHD.

Two treatment groups were formed. The comprehensive clinical care (CCC) group intervention included stimulant medication (Ritalin), parent counseling (in both individual and group formats), and school consultation. The EEG group intervention contained all of the components of the CCC group intervention with the addition of EEG biofeedback. Parental consent and child assent were not mentioned, but children were assigned to treatment groups based on parent choice. All participants were placed on Ritalin. About 1 week after their first dose, participants were readministered the TOVA. The TOVA continued to be readministered until correct dosage of Ritalin was determined for each participant. Parent counseling encompassed a 10-session parenting class and individual counseling as needed. Parents learned about the causes of ADHD and how to use positive parental attention and reinforcement to reduce symptoms at home. School consultation involved an evaluation of each participant by their school districts in accordance with the Individuals with Disabilities Act and the Rehabilitation Act of 1973. Each participant received an individualized education program or a plan of academic support/accommodation ("504 Plan"), which was revised with the authors' assistance.

For the participants in the EEG group, 30-min to 40-min weekly EEG biofeedback sessions were provided. These sessions continued until each participant's cortical slowing on the QEEG scan registered as within 1 *SD* of their age peers and they could maintain this for three consecutive 40-min sessions. Participants took between 34 and 50 sessions to do this. The EEG biofeedback followed the Lubar Protocol (Lubar et al., 1995). Participants were trained to decrease theta (4–8 Hz) bands or to increase beta (16–20 Hz) bands. Visual and auditory feedback rewards included an interactive visual display and a tone. Task difficulty was increased if participants reliably acquired more than 25 rewards per minute.

Two posttreatment outcome measures were administered for all participants: the first 1 year after the pretreatment measures and the second 1 week after that. The extra week served as a "washout" period in which no medications were taken by participants. Posttreatment measures included the QEEG scan, the TOVA, and the ADDES (Home and School).

There were no significant differences between groups on pretreatment measures. Parents and teachers reported no sustained improvement from the CCC group regardless of medication or parenting style but reported sustained improvement for the EEG group regardless of medication. Significant interaction effects appeared between posttreatment parent behavioral measures for parents in the EEG group who systematically used reinforcement and parents who did not. Participants of the EEG group whose parents consistently used reinforcement strategies demonstrated reduced hyperactivity and impulsivity and improved attention at home. Parenting style effects on behavior were not apparent in teacher reports, however. The QEEG scanning process indicated that after treatment, the EEG group displayed significantly less cortical slowing than the CCC group. Both groups improved significantly on mean TOVA scores. Both groups' scores were not in the ADHD range. The CCC group, however, lost those gains when the stimulant medication was removed. The EEG group retained those gains after the medication stopped. These results indicate that EEG biofeedback may be an effective treatment for ADHD and may be more effective than stimulant medication.

Fuchs et al. (2003). The Fuchs et al. (2003) study population consisted of a sample of 34 German children (ages 8–12) independently diagnosed with ADHD by two clinicians using *DSM–IV* critieria (American Psychiatric Association, 1994). None of the children had been treated for ADHD before the study. Parental consent and child assent were not mentioned, but children were assigned to treatment groups based on parent choice. Two treatment groups were created: a neurofeedback training (NFT) group ($n = 22$) and a methylphenidate group ($n = 12$). One participant of the methylphenidate group dropped out due to side effects. Both treatments were conducted over a period of 12 weeks. The methylphenidate group received medication three times a day on school days during the treatment period. Doses were individualized to each participant.

The NFT group had three sessions per week with 30 to 60 min per session for a total of 36 sessions. The NFT participants were directed to "increase the power in the SMR or beta1 bands ('reward bands') and simultaneously to decrease the power in the theta and beta2 bands ('inhibit bands')" (Fuchs et al., 2003, p. 3). The SMR bands were used with participants with the hyperactive-impulsive subtype of ADHD, and beta1 bands were used with participants with the inattentive subtype of ADHD. Participant neurofeedback responses were displayed on a computer monitor in the form of "Pac-Man-type" maze games.

Outcome measures were administered before and after the 12-week treatment period. Participants were administered the TOVA, The Attention Endurance Test, and the WISC–R, whereas parents and teachers were given a German version of the Conners Behavior Rating Scale. Teachers were blind to the treatment type each participant received.

The outcome measures indicated significant improvement for both groups on all four subscales of the TOVA. Both groups demonstrated an ability to work on more items with fewer mistakes in the Attention Endurance test. Participants improved on accuracy scores, speed scores, and the composite total score. Improvements were also apparent on the IOWA-Conners Behavior Rating Scale for both groups. Parents and teachers noted a reduction in ADHD behaviors after both treatments. Improvements on the WISC–R were relatively small, however and equivalence tests were not significant. These results indicate that both neurofeedback training and methylphenidate may be effective treatments for ADHD. The researchers note that the groups were not randomly assigned and that parents might have been more motivated in the interventions that they chose for their children. The authors recommend more research with larger samples and a longer term study.

Rossiter (2004). The Rossiter (2004) involved a sample of 62 individuals (ages 7–55 years) diagnosed with ADHD by the author using *DSM–IV* criteria. Two treatment groups were formed based on the types of treatment the participants received. Thirty-one of 33 individuals treated with neurofeedback (EEG) were included in the neurofeedback (NF) group. Two individuals were excluded because they were also taking antidepressant and/or antihypertensive medication. Six individuals in the NF group were taking stimulant medication during treatment but stopped medication 2 days before pretreatment measures and posttreatment measures. Four of those participants stopped medication during treatment and were drug free for 6 weeks before posttreatment measures. Eight participants had previously taken stimulant drugs but had stopped 6 months before. The second treatment group (the medication group) consisted of 31 individuals drawn from a pool of 64 people treated with either methylphenidate or dextroamphetamine stimulants who had taken the TOVA. The participants were drawn to match the NF group participants based on TOVA scores, IQ, gender, and ADHD diagnosis. The participants had chosen which treatment they wanted.

The NF group participated in 40 neurofeedback sessions for office patients and 60 or more sessions for home patients over a course of 3 months. In the NF group, participant presenting problems determined the type of neurofeedback used. Rossiter (2004) described the training:

> Patients presenting with inattention, daydreaming, poor sustained attention, and/or lack of motivation received left hemisphere training with the active electrode at C3 (International 10–20 System, Jasper, 1968) using enhance 15–18 Hz protocols. The C3 default inhibit band was initially 4–7 Hz and later 2–7 Hz. When the baseline EEG showed excessive alpha (8–11 Hz), an 8–11 Hz or 2–10 Hz inhibit band was used. Patients with symptoms of impulsivity, distractibility, and/or stimulus-seeking behaviors received right hemisphere training with the active electrode at C4 using enhance 12–15 Hz protocols. The C4 default inhibit band was initially 4–7 Hz and later changed to 2–7 Hz. The neurofeedback software was programmed to control eye movement and EMG artifact. Inattentive type AD/HD patients ($n = 15$) received left hemisphere (C3) training. Combined type AD/HD patients ($n = 16$) started each session with left hemisphere (C3) training and finished with right hemisphere (C4) training. (p. 237)

See Rossiter (2002) for further details on neurofeedback procedures, involving the use of a C3/Beta protocol and a C4/SMR protocol. The visual and auditory feedback provided to participants was based on "the ratio of slow wave activity to be suppressed divided by fast wave activity to be enhanced" (Rossiter, 2002, p. 9).

The medication group was tested before beginning medication and then 3 to 7 days after medication began to determine dosage. Once the maintenance dose was found, no more outcome measures were taken for the medication group. The NF group participants were assessed using three outcome measures before and after treatment: the TOVA, the BASC, and the Brown Attention-Deficit Disorder (ADD) Scales. The medication group participants were assessed only using the TOVA.

Both the NF group participants and the medication group participants displayed significant improvement on TOVA scores from pretreatment to posttreatment. The gains achieved by each group were not significantly different from each other. Only the NF group participants were given additional outcome measures. The NF participants also achieved significant improvement on Bask and Brown ADD Scale scores. Both home and office NF participants displayed similar posttreatment gains. These results indicate that both NF and stimulant medication may be effective treatments for ADHD.

Drechsler et al. (2007) and Doehnert et al. (2008). The Doehnert et al. (2008) and the Drechsler et al. (2007) articles reported results from one study, with the Drechsler et al. article containing the primary report. The study population consisted of a sample of 30 children (ages 9–13) diagnosed with ADHD (American Psychiatric Association, 1994) by a prior formal diagnosis and confirmed by HYPESCHEME, a computerized checklist and diagnostic algorithm for the ICD-10 and the *DSM–IV*. Parental informed consent and child assent were obtained. They were assigned to one of two groups by nonrandom methods, with 17 in the experimental (NFT) group and 13 receiving cognitive behavior therapy, with some of the CBT patients also receiving stimulant medication. The parents of participants on medication were asked to keep the medication constant through the NFT to avoid interfering medication effects. The participants on medication stopped taking it at least 24 hr before neuropsychological testing. Group therapy took place in groups of five to six children for 14 to 15 sessions of 90 min, 1 to 2 sessions per week. The participants were trained to regulate cortical activation.

The experimental group received NFT of SCPs. Participants in the NFT group were taught to control their cortical activation by increasing positivity (decreased cortical activation) and negativity (increased cortical activation) over their sensorimotor cortex. The intervention took place in the form of a computer game. Thirty sessions of NFT were carried out over a 10-week period. Children participated in 20 sessions the first 2 weeks with two 45-min sessions every weekday. In the next 5 weeks the participants had a break from NFT but practiced with transfer training cards at home. The final 10 sessions took place in double sessions once or twice a week over a 3-week period.

Pre- and posttreatment outcomes were taken before NFT started and after NFT finished. The instruments used to assess pre- and posttreatment outcomes were EEG and event-related potential recordings to measure CNV amplitude, German standardized *DSM–IV* questionnaire for ADHD (FBB-HKS), CPRS, BRIEF, Child Behavior Checklist, Conners' Teacher Rating Scale, Teacher's version of the BRIEF, German WISC–III, Alertness (a subtest of TAP), Go/NoGo (a subtest of TAP), D2 (test of focused and selective attention), Score! (a subtest from the Tea-ch), and Code transmission (Tea-ch; test of sustained attention).

According to parent ratings, both NFT and group therapy groups improved, though the NFT group improved more in terms of cognitive regulation. According to teacher ratings, only the NFT group improved, though improvement was not as much as parents described. Both groups showed significant improvements on neuropsychological measures. In the Go/NoGo inhibitory control task, both groups improved, with the group therapy group appearing less impaired than the NFT group. Participants with ADHD learned how to control cortical regulation and increased cortical activation (i.e., negativation), but positivation remained steady throughout the study—no significant improvement was made. Researchers indicated that this was acceptable and that negitivation was the main goal of the training. Most of the participants could not distinguish between positivity and negativity without neurofeedback, however. This suggests that the participants may not be able to translate the cortical activation or deactivation skills learned into daily life. The researchers note that parental support may have been a contributing factor to the behavioral results of the neurofeedback training.

Twenty-six of the 30 children who participated in the study (14 in the NFT group and 12 in the group therapy group) had completed EEG mapping assessments before and after the intervention. These results were examined in the Doehnert et al. (2008) article. Reductions of the CNV during cortical activation are common in people with ADHD (Doehnert et al., 2008). The researchers expected to find an improvement in CNV for participants who were in the NFT group, but that was not the case. Researchers note that participants who performed well in the NFT had less CNV reduction than those who did not. Researchers hypothesize that the NFT group may have lacked motivation due to boredom with the repetitive laboratory tasks required for the NFT. Researchers note limitations such as small groups, no random assignment, premeasurement group differences, and the possibility that a cognitive behavioral therapy group may not have been an appropriate control group for the NFT group. The authors call half of the NFT group "nonresponders," though no further explanation is given for this term. It may refer to how the authors sorted the NFT participant data into two groups: good performers and bad performers. The authors conclude that the behavioral effects of SCP neurofeedback were due to both specific effects of neurofeedback and nonspecific factors. The researchers suggest that more research is needed.

Experimental Designs

Linden et al. (1996). The Linden et al. (1996) sample consisted of 18 children (ages 5–15) diagnosed with ADHD or ADD (American Psychiatric Association, 1987). Six of the participants also had learning disabilities. Participants neither took medication for ADHD nor engaged in any other ADHD intervention for the duration of the study (6 months). The participants were randomly assigned to two groups: EEG biofeedback and waiting-list control. The members of the control group were on a waiting list to receive the treatment at the end of the study (6 months). There were 9 participants in each group, each with an equal number of ADD/ADHD ($n = 6$) and ADD/ADHD with learning disabilities ($n = 3$) participants. The individuals who scored the rating scales were blind to participant group assignments.

The EEG group received 40 sessions over the course of 6 months. Each session was made up of three 10-min EEG biofeedback segments and lasted for 45 min. Participants had 2 sessions per week. Participants were trained to decrease theta (4–8 Hz) bands or to increase beta (16–20 Hz) bands while performing one of three tasks: standard biofeedback with visual and auditory feedback rewards, a reading task, and an auditory listening task. Visual and auditory feedback rewards were displayed on computer monitors and streamed through audio speakers. Gradually, theta thresholds were decreased and beta thresholds were increased. Participants were given small rewards (e.g., baseball cards or stickers) at the end of each session based on their performance, effort, and level of cooperation.

Outcome measures were taken before treatment and at the end of treatment 6 months later. Outcome measures included the Composite IQ score on the KBIT, the parent Conners Behavior Rating Scale, and the parent SNAP behavior rating scale index for inattentive behaviors. EEG data were not analyzed because some of the equipment used to collect the EEG data was unreliable due to equipment restrictions.

Posttreatment outcome measures indicated that EEG group IQ scores significantly improved from pretreatment measures. These posttreatment improvements were on average 9 points higher than the control group. The behavioral rating measures for the EEG group indicated a significant reduction in inattentive behaviors and no significant differences reduction in hyperactivity or aggressive/defiant behavior. The authors note that although the hyperactive behavior scores were not statistically significant, they were clinically significant because the posttreatment scores fell below the cutoff point that is usually used to determine hyperactivity. The control group registered no significant improvement on any of the measures from pretreatment measures to posttreatment measures. The authors note that a power analysis indicated that all measures had enough power except hyperactivity measures using a critical value of .80. The study's results indicate that EEG biofeedback may be useful for reducing inattention symptoms of ADHD.

Carmody et al. (2000). The Carmody et al. (2000) study population consisted of a sample of 16 children (ages 8–10). Eight children were diagnosed with ADHD (American Psychiatric Association, 1994) by a school psychologist. The children with ADHD were matched by age, gender, and grade in school with 8 children who were not diagnosed with ADHD. Parental consent and child assent were obtained. The matched pairs of participants were randomly assigned to one of two groups: experimental ($n = 8$) or control ($n = 8$). Both groups had 4 children with ADHD and 4 children without ADHD. The control group was on a waitlist for the treatment and received no treatment for the course of the intervention. The experimental group received NFT. The participants did not take medication during the study.

The NFT was carried out over a 20- to 24-week period with 3 to 4 training sessions per week for a total of 36 to 48 sessions. The training period lasted from January to May. Each session lasted for 30 min. In the first 13 to 35 sessions, the participants were trained to suppress the amplitude of their delta-theta waves (2–7 Hz) and increase the amplitude of their beta waves (16–18 Hz), but some of the ADHD participants displayed signs of overstimulation (behavior problems) so the ADHD participants switched training protocols. The ADHD participants were then trained to enhance the amplitude of the SMR (13–15 Hz) and suppress the amplitude of delta-theta activity (2–7 Hz). The participants without ADHD remained on the original training protocol. The intervention took place in the form of a video game.

Outcome measures were administered three times: in January, March, and June. The instruments used to assess outcomes were the TOVA and the ADDES (1989). The TOVA was taken by the participants, and the ADDES was completed by teachers or paraprofessionals who worked directly with the participants.

The outcome measures indicated improvement in inattention based on teacher ratings in the ADDES and a significant reduction of errors of commission and anticipation in the experimental group. This may be an indication of a reduction in impulsivity. There were no significant changes in impulsivity and hyperactivity based on teacher reports in the ADDES. The researchers noted a number of limitations, including teacher doubts about the effectiveness of behavioral treatments on child behaviors, and the added benefits the experimental group had which the control group did not display (e.g., increased attention, biofeedback, rewards for improvement, etc.). The authors recommend more research before any associations are made between improvement in these areas and the use of NFT.

Beauregard and Levesque (2006) and Levesque et al. (2006). The Beauregard and Levesque (2006) and Levesque et al. (2006) articles reported results from the same study. The study population consisted of a sample of 20 children (ages 8–12) diagnosed with ADHD (American Psychiatric Association, 1994) by a certified child psychologist. Written informed consent was obtained from the parents of the children. They were randomly assigned to one of two groups: experimental (neurofeedback training, $n = 15$), or control (no treatment, $n = 5$). Participants did not take psychostimulant drugs during the study, although participants in both groups received methylphenidate before the study began.

The NFT was carried out over a 13½-week period with 3 training sessions per week for a total of 40 sessions. Each session lasted for 1 hr. In the first 20 sessions, the participants were trained to "enhance the amplitude of the sensorimotor rhythm (SMR) (12–15 Hz) and decrease the amplitude of theta activity (4–7 Hz)" (Beauregard & Levesque, 2006, p. 6), whereas in the second 20 sessions, the participants were trained to "inhibit the amplitude of their theta waves (4–7 Hz and increase the amplitude of their beta 1 waves (15–18 Hz)" (Beauregard & Levesque, 2006, p. 6). Feedback was provided in the form of a video game.

Pre- and posttreatment outcomes were taken 1 week before NFT started (Time 1) and 1 week after NFT finished (Time 2). The instruments used to assess pre- and posttreatment outcomes were the Digit Span subtest of the WISC–R, the IVA, and the Conners' Parent Rating Scale–Revised. fMRI was also conducted at Time 1 and Time 2, whereas participants participated in a Counting Stroop task and a Go/No-Go task.

The pretreatment outcome measures indicated that there was no significant difference between the experiment and control groups prior to the intervention. The fMRI scans indicated a significant activation of the right anterior cingulated cortex from Time 1 to Time 2 in the experiment group but not the control group. This suggests that NFT can be used to normalize the functioning of the anterior cingulated cortex in individuals with ADHD. The anterior cingulated cortex is important in selective attention (Levesque et al., 2006). The posttreatment outcome measures indicated no significant difference for the control group compared to Time 1. For the experiment group, the Digit Span and IVA scores increased significantly from Time 1 to Time 2, and the Inattention and Hyperactivity components of the CPRS–Revised decreased significantly from Time 1 to Time 2. These outcome measures indicate that NFT may be an effective treatment for ADHD. With a control group size of 5 participants, results should be interpreted with caution.

Gevensleben, Holl, Albrecht, Vogel, et al. (2009) and Gevensleben, Holl, Albrecht, Schlamp, et al. (2009). The Gevensleben, Holl, Albrecht, Vogel, et al. (2009) and the Gevensleben, Holl, Albrecht, Schlamp, et al. (2009) articles reported results from one individual study involving 94 children (ages 8–12) diagnosed with ADHD (American Psychiatric Association, 1994) by a child and adolescent psychologist or a clinical psychologist, supervised by a board-certified child and adolescent psychiatrist. Children were excluded if they had comorbid disorders besides conduct disorder, emotional disorders, tic disorder, and dyslexia. The participants were therapy free and drug free for at least 6 weeks before the intervention started. Most of the children had never taken drugs before ($n = 87$). The written informed consent was obtained from the parents of the children and assent was obtained from the children. Participants were randomly assigned to one of two groups: NFT or attention skills training (AST). The NFT group originally had 64 members and the AST group originally had 38 members, but the NFT group lost 5 participants and the AST group lost 3 participants. Therefore, 94 participants were included in the analysis: 59 in the NFT group and 35 in the AST group. The AST was designed to mirror the NFT as much as possible.

Both groups participated in the same study design, the difference being in the type of treatment received. Both NFT and AST groups participated in two blocks of 18 sessions each. Two to three double sessions were conducted per week. Each session lasted about 50 min. Each session consisted of tasks that looked like computer games (about 25–30 min), and participants were assigned 10-min homework practice sessions in daily-life situations. Each block lasted 3 to 4 weeks. The NFT protocol changed for each block: There was an SCP block and a theta/beta block in balanced order. For the SCP block, NF participants were trained to increase cortical activation (negativity) and to decrease cortical activation (positivity) by moving a ball up and down on the screen. For the theta/beta block, NF participants were trained to suppress theta bands and increase beta bands by reducing and increasing bars on the screen. Trials without feedback (transfer trials) were also conducted. The AST participants participated in computer tasks which exercise vigilance, sustained attention, reactivity, and visual and auditory perception. The AST participants were also directed to practice skills in daily-life situations.

There were three periods of assessment: 1 week before the intervention (pretreatment), 1 week after the last session of the first block (intermediate), and 1 week after the intervention (posttreatment). Parent and teacher behavior ratings included the German ADHD rating scale (FBB-HKS), the German Rating Scale for Oppositional Defiant/Conduct Disorders (FBB-SSV), and the German version of the SDQ. Parents additionally filled out the German version of the Home Situations Questionnaire and the German version of the Homework Problem Checklist.

Parent ratings indicated that both groups improved significantly on the German ADHD rating scale (FBB-HKS) but that the NFT group improved significantly more than the AST group with a medium effect size of .60 (Cohen's *d*). Teacher effect sizes were in the same range for this measure. Teachers also indicated significant improvement for the NFT group compared to the AST group, particularly in the inattention subscale. Parents also rated NFT participants significantly improved compared to AST participants on the German Rating Scale for Oppositional Defiant/Conduct Disorders (FBB-SSV), but teacher ratings displayed no significant improvement for either group. Both parents and teachers rated the NFT group significantly more improved than the AST group on the SDQ. Both groups demonstrated improvement on the Home Situations Questionnaire and the Homework Problem Checklist, but the groups did not differ significantly from each other. These results seem to indicate that AST may result in some improvement in ADHD symptoms but that NFT results in more improvement than AST.

The Gevensleben, Holl, Albrecht, Schlamp, et al. (2009) article further analyzed the differences between the SCP and beta/theta protocols using EEG data. Twenty-two participants from the study were excluded from this analysis due to poor EEG signal quality. The analysis indicated that neurofeedback led to a decrease in theta activity and that the reduction was comparable in both SCP and theta/beta blocks but that neither block was significant on its own. The authors discuss the need for more research on how to adjust NFT protocols for optimum results. The authors also note that it may be beneficial in the future to extend the 18 session training blocks.

DISCUSSION

All nine studies produced results that are consistent with the hypothesis that neurofeedback may be an effective treatment for ADHD. Neurofeedback treatment may not be more effective than alternative treatments however. Six of the nine studies reviewed compared neurofeedback to alternative treatments. Study results indicated alternative treatments may also be effective treatments for ADHD. When discussing studies that compare neurofeedback treatment with stimulant medication, Sherlin, Arns, Lubar, and Sokhadze (2010) noted that "the effects of these studies demonstrate similar treatment responses between stimulant medication and neurofeedback" (p. 69). The authors cautioned, however, that the effects of medication were not sustained when the medication was removed, as illustrated in the comprehensive clinical care group in Monastra et al. (2002). Medication effects were also discussed in Jensen et al. (2007). Jensen et al. found that an intensive medication program resulted in a significant improvement over behavior therapy and community care treatments for the first 3 years, though the effects declined during the 3rd year of treatment. Nevertheless, participants in all treatments improved significantly from baseline to the end of the 36-month study. The authors noted that this may be attributable to a decline in treatment compliance in the medication group. In studies in which medication is maintained over time, it may be beneficial to follow up with participants after 3 years to reassess the effectiveness of medication versus neurofeedback treatment in participants with ADHD.

The results of this review indicate that neurofeedback may be an effective treatment for ADHD, but additional rigorous studies are needed to provide further support for this treatment method. Future research might be directed toward comparing neurofeedback with a near identical placebo treatment similar to that of Gevensleben, Holl, Albrecht, Vogel, et al. (2009) and the Gevensleben, Holl, Albrecht, Schlamp, et al. (2009).

The types of neurofeedback treatment administered (i.e., the neurofeedback protocols) differed among studies. Gevensleben et al. (2009) investigated ways to adjust the neurofeedback training for the best results, but no conclusions were made in this area. More research is needed to determine if one neurofeedback protocol is more effective over others.

Although all studies contained behavioral outcome measures, in some studies only the neurofeedback group was administered the behavioral measures (Rossiter, 2004; Rossiter & La Vaque, 1995). For these studies, the alternative treatment groups were only administered the TOVA. Although these results demonstrated improvement on an exam, it is unknown whether the improvements were also apparent in participant behavioral conduct. Results from Doehnert et al. (2007) indicate that NF participants may not be able to translate laboratory skills into daily life, though participants displayed behavioral improvement. Many of the parents reported on behavioral conduct on participants, though in some cases (Fuchs et al., 2003; Doehnert et al., 2007; Drechsler et al., 2008; Monastra et al., 2002) parents chose the type of treatment that participants were administered. It was not possible to blind parents to treatment assignment.

Studies suffered from small sample sizes (e.g., Carmody et al., 2000; $n = 16$) with six of the nine studies containing fewer than 50 participants. This effects the generalizability of the results.

More research is needed with larger sample sizes, more randomized control trials, and with a standard neurofeedback treatment protocol. More research is also needed to identify if one neurofeedback protocol is more effective than others and to compare neurofeedback to alternative treatments to determine which treatments are the most effective for ADHD.

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