Neurofeedback and Cognitive Attention Training for Children with Attention-Deficit Hyperactivity Disorder in Schools

Naomi J. Steiner, MD,* Elizabeth C. Frenette, MPH,* Kirsten M. Rene, MA,*
Robert T. Brennan, EdD,† Ellen C. Perrin, MD*

ABSTRACT: ***Objective:*** **To evaluate the efficacy of 2 computer attention training systems administered in school for children with attention-deficit hyperactivity disorder (ADHD).** ***Method:*** **Children in second and fourth grade with a diagnosis of ADHD (n = 104) were randomly assigned to neurofeedback (NF) (n = 34), cognitive training (CT) (n = 34), or control (n = 36) conditions. A 2-point growth model assessed change from pre-post intervention on parent reports (Conners 3-Parent [Conners 3-P]; Behavior Rating Inventory of Executive Function [BRIEF] rating scale), teacher reports (Swanson, Kotkin, Agler, M-Flynn and Pelham scale [SKAMP]; Conners 3-Teacher [Conners 3-T]), and systematic classroom observations (Behavioral Observation of Students in Schools [BOSS]). Paired *t* tests and an analysis of covariance assessed change in medication.** ***Results:*** **Children who received NF showed significant improvement compared with those in the control condition on the Conners 3-P Attention, Executive Functioning and Global Index, on all BRIEF summary indices, and on BOSS motor/verbal off-task behavior. Children who received CT showed no improvement compared to the control condition. Children in the NF condition showed significant improvements compared to those in the CT condition on Conners 3-P Executive Functioning, all BRIEF summary indices, SKAMP Attention, and Conners 3-T Inattention subscales. Stimulant medication dosage in methylphenidate equivalencies significantly increased for children in the CT (8.54 mg) and control (7.05 mg) conditions but not for those in the NF condition (0.29 mg).** ***Conclusion:*** **Neurofeedback made greater improvements in ADHD symptoms compared to both the control and CT conditions. Thus, NF is a promising attention training treatment intervention for children with ADHD.**

(*J Dev Behav Pediatr 35:*18–27, 2014) **Index terms:** neurofeedback, ADHD, classroom observations, computer attention training, school intervention, growth modeling.

Attention-deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder with core symptoms of hyperactivity, impulsivity, and/or inattention and frequently includes executive functioning impairments.[1] In the United States, the prevalence is 9.5% for 4- to 17-year olds.[2] Children with ADHD experience attention and behavior challenges at school, leading to poor academic outcomes[3] with higher rates of physical and verbal aggression, seeking attention from the teacher and noncompliance than their comparison peers.[4] Children with ADHD are 3 to 7 times more likely to use special education services, to be expelled or suspended, or to repeat a grade than children without ADHD.[5]

From the *The Floating Hospital for Children at Tufts Medical Center, Department of Pediatrics, Boston, MA; †Harvard School of Public Health, Boston, MA.

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Address for reprints: Naomi J. Steiner, MD, Floating Hospital for Children at Tufts Medical Center, 800 Washington Street, Box #854, Boston, MA 02111; e-mail: nsteiner@tuftsmedicalcenter.org.

Community treatments, such as medication and/or behavioral therapies, are viable treatment options for children with ADHD; yet they are also associated with significant limitations. Medication frequently improves symptoms, although it may not lead to complete normalization of symptoms, and long-term adherence to medication as prescribed varies between 13.2% and 64%,[6,7] with long-term effectiveness yet to be found.[8] When medication is discontinued, symptoms usually return. Furthermore, some children (20–30%) do not show clear benefit and/or experience adverse effects from stimulant medication,[9,10] such as decreased appetite, insomnia, and growth suppression, which has been reported to reverse only after stopping medication.[10–12] Therefore, some parents do not wish to medicate their children.[13]

Empirically supported psychosocial treatments for ADHD include parent behavioral training and behavioral classroom interventions.[14,15] Other psychosocial treatments, such as academic interventions,[16,17] the Summer Treatment Program for children with ADHD,[18] and programs that combine parent training and child social skills training have also shown promise for improving ADHD-related impairment.[14] However, psychosocial interventions on their own have not shown to be as effective as medication,[19] and improvements may not be generalized to all contexts or last beyond the intervention trial.[20] The pervasiveness of ADHD symptoms in the classroom, along with community treatment limitations, highlights the importance of continuing to investigate alternative treatments that can be implemented in schools, such as computer attention training (CompAT). Based on theories of brain plasticity and operant conditioning, CompAT interventions are designed to improve core skills typically deficient in children with ADHD. Two main types include neurofeedback (NF) and cognitive training (CT).[21]

Findings from electroencephalograms (EEG) of children with ADHD frequently show increased theta activity (which represent a drowsy state) and increased theta-to-beta ratio in the frontal cortex.[22] Therefore, one of the most frequently used NF approaches trains participants to increase their beta waves (which represent an attentive state) and suppress their theta waves.[22] Neurofeedback gives immediate feedback on how the brain is focusing, as evidenced by these specific brainwave patterns. The changes in brainwave patterns are represented on the computer screen by moving characters or figures along with auditory feedback. With practice, participants learn to alter their brainwaves to obtain a goal, reinforcing the state of attention.[23] Previous research supports the efficacy of NF as a treatment for children with ADHD.[24]

Cognitive training uses on-going computer feedback to reinforce correct responses, thus training attention and working memory and decreasing impulsivity. Interventions of CT have been found to improve working memory and decrease parent- and teacher-rated symptoms of ADHD.[25] Training working memory has also shown improvements in tasks using this skill such as mathematical problem solving and reading comprehension.[26]

Gevensleben et al[27] found significant ADHD symptom improvements on parent behavior rating scales in a NF condition that were superior to a CT condition from pre- to postintervention. However, an unbalanced sample size makes the generalization of these results unclear. Furthermore, a recent meta-analysis of nonpharmacological treatments for ADHD concluded that more evidence is needed for both NF and CT before they can be supported as treatments for ADHD because studies generally had small sample sizes, lacked control conditions, and were usually conducted in a laboratory or clinic setting.[27–29]

The primary aim of this study was to evaluate the efficacy of NF and CT for children with ADHD in a school setting. This is the first randomized control efficacy trial that has implemented a NF intervention in a school setting and the second that has implemented a CT intervention in a school setting.[30]

We hypothesized that (1) both interventions would result in improved attention and executive functioning compared to the control condition, as measured by parent and teacher questionnaires; (2) both interventions would result in decreased off-task behavior and increased engagement in the classroom compared to the control condition, as measured by a systematic double-blinded classroom observation; and (3) participants in the NF condition would show greater improvements in ADHD symptoms and classroom behavior compared to children in the CT condition.

METHODS

Sample Size and Randomization Procedures

An a priori power analysis with an alpha of .05 and power of 80%, using effect sizes from our pilot study,[21] determined that the smallest sample size adequate to detect moderate effect sizes between conditions would be 44 participants per condition. The research coordinator enrolled participants, balanced them by school district, gender, and medication status, and then assigned them via a computer random number generator into the 3 conditions (neurofeedback [NF], cognitive training [CT], and control). School personnel would have considered it unethical to remove students from the classroom for a sham condition; therefore, a control condition was chosen. The control condition received computer attention training (CompAT) treatment the following school year. Teachers were informed if their student was in the control versus a treatment condition but not the specific intervention condition.

Participants

This trial took place in 19 public elementary schools in the Greater Boston area, providing a diverse range of settings and students. The first cohort of participants was enrolled from May to October 2009, followed by the intervention from November through April 2010. This procedure was repeated the following year for a second cohort. Second and fourth grade students were chosen as the target population because it was important to maintain sampling independence so that students from each school could only be eligible for the study once. Participants were eligible if they met the following inclusion criteria: (1) clinical diagnosis of attention-deficit hyperactivity disorder (ADHD) per DSM-4 made by the child's clinician (e.g., primary care physician or psychologist), (2) child in second or fourth grade, and (3) ability to speak and understand English sufficiently to follow the intervention protocol, although English need not be their first language. In order to increase external validity of running a school-based intervention, children were included regardless of medication status. All participants were informed to continue with scheduled clinician visits and standard community treatments independent of study participation. Thus, the control condition was considered a true "community treatment" condition, where students received standard care as offered in their community[31] rather than a "no-treatment" condition, where children would not be taking medication or receiving therapy. Children with a coexisting diagnosis of conduct disorder, autism spectrum disorder, or other serious mental illness (e.g., psychosis) or with an intelligence quotient <80 measured by the Kaufman Brief Intelligence Test were excluded to limit possible confounding factors and extensive amendments to the intervention protocol that could affect standardized implementation. Written informed consent and child assent were obtained, and this study was approved by the Tufts Medical Center Institutional Review Board.

Interventions

Research assistants (RAs) received standardized training to administer NF and CT interventions, including direct observation assessments and a post-training test. Extensive care was given during training to inform RAs that both interventions were considered to be clinically equal to minimize bias of RAs, teachers, and parents. The session procedures for both interventions were identical. Both NF and CT participants received three 45-minute intervention sessions per week for a total of 40 sessions, conducted at a 2:1 or 1:1 student-to-RA ratio depending on logistics, over a 5-month period at school. The sessions occurred throughout the school day at times that would best accommodate each student's academic schedule. During sessions, minimal help from the RA was given unless the child was not progressing with exercises. A standardized session checklist was completed by RAs at each session for each child to monitor implementation fidelity, and small tangible incentives were provided at the end of each session with a prize given at the end of the 40 sessions.

The NF intervention system used[32] trains the child to increase beta waves and suppress theta waves. This system uses EEG sensors that are embedded in a typical looking bicycle helmet, without requiring conductive gel, significantly easing delivery to children on a large scale. When the theta-to-beta ratio decreases, reflecting effective focusing, the participant progresses on the exercise. For example, in 1 specific exercise, as the theta-to-beta ratio decreases, a dolphin character swims down to the bottom of the ocean to collect coins from a treasure chest, and the child earns points. If the child becomes distracted, the dolphin swims back up to the surface of the ocean.

The CT intervention system used[33] includes an array of cognitive exercises. We used those that target areas of attention and working memory. For example, in 1 exercise, as participants match letter-number pairs correctly, a safe becomes unlocked, and children win a virtual prize. The tasks become more challenging as the participant progresses. Automatic progress from one exercise to the next makes it possible to deliver the intervention on a larger scale. The exercises are both auditory and visual, and users are able to design their own custom exercise protocols. For this study, we created a standardized protocol with 14 different age-appropriate exercises that were done on a rotating basis incorporating visual tracking, reaction time, inhibition control, and working memory skills.

Outcome Measures

All outcome measures were completed by parents, teachers, and blinded classroom observers at pre- and postintervention. The Conners-3 Parent (Conners 3-P) rating scale is a validated and standardized instrument used to assess ADHD symptomatology.[34] It includes a Global Index and 8 subscales, 2 of which evaluate the study-targeted areas: Inattention and Executive Functioning.

The Behavior Rating Inventory of Executive Function (BRIEF) parent rating scale is a validated and standardized instrument that assesses executive functioning.[35] It includes 8 subscales that are combined into 2 indices (Behavior Regulation and Metacognition), which are summed together in the Global Executive Composite.[36]

The Swanson, Kotkin, Agler, M-Flynn and Pelham scale (SKAMP) is a validated teacher observation rating scale that focuses on factors that predict social constructs and test-based academic achievement.[37] The scale includes 10 items averaged into a total score and divided into both classroom Attention and Deportment subscales.[38]

The Conners-3 Teacher (Conners 3-T) rating scale is a validated and standardized instrument used to assess ADHD symptoms through teacher observation of classroom behavior.[34] The short form includes 5 subscales, one of which examines a study-targeted area: Inattention.

The Behavioral Observation of Students in Schools (BOSS) is a systematic observation method for coding classroom behavior[39] and reports on engagement (active or passive) and off-task behaviors (motor, verbal, and passive). Engagement and motor/verbal off-task behaviors are reported in the current study. The BOSS has been found to be reliable between observers,[40] to differentiate between children with ADHD and their typically developing peers and to be sensitive to treatment effects.[40,41] Prior to conducting observations for the study, assessment RAs followed a detailed training protocol for the BOSS,[42] leading to high post-training interrater reliability ($\kappa > .80$). These RAs then conducted three 15-minute classroom observations per participant at both pre- and post-intervention and were unaware of participants' randomization condition. Participants were unaware that they were being observed.

A Medication Tracking Questionnaire, developed by the research team, was used to identify medication type, dosage, and history. Stimulant medications were converted into methylphenidate (MPH) equivalencies to compare dosage. Amphetamine mixed salts is twice as potent as MPH (e.g., 10 mg of amphetamine mixed salts is considered equivalent to 20 mg of MPH). Reliability of responses was assessed by comparing responses at each time point, and ambiguous responses were clarified by direct communication with parents and pediatrician offices.

Data Analysis

Following the intent-to-treat model, all enrolled participants were included in analyses. Missing items within multi-item scales were resolved using expectation maximization imputation, which is an iterative imputation method suitable for low-frequency missing data and/or when standard errors are not of primary concern.[43] Fully missing questionnaires were addressed directly through the analytic strategy described below. Descriptive statistics for demographic variables and baseline data were calculated, and analyses of variance were used to analyze baseline differences among the 3 conditions. Cohen's *d* effect sizes were calculated to analyze changes in scores from pre- to postintervention.

Changes in parent- and teacher-reported measures and classroom observations were investigated using a multilevel growth modeling approach[44] to assess change pre- and postintervention, comparing intervention conditions to the control, with post hoc comparison tests to compare the 2 intervention conditions. Our model addresses long-held reservations about estimating change over time using just 2 time points as opposed to 3 or more time points by incorporating information about the reliability of measures into the model.[45] Our approach uses data from 2 parents to estimate reliability of both the point estimates and the changes on the Conners 3-P and the BRIEF.[46] For the Conners 3-T, a weighting scheme based on the reliability estimates obtained from the analysis of the Conners 3-P was used to incorporate the measurement model.[44] Reliability estimates for the SKAMP were estimated using individual items within the measure.[47] For the BOSS, data from all 3 observations were used to estimate reliability. Not only do these models allow for the estimation of reliability of measurement and change within the overall estimation but also they are flexible in that they can accommodate unbalanced data. A participant can be included at a time point even if only 1 parent questionnaire was available or if we did not have complete data on the subject (e.g., a missing subscale or an entire missing time point).

As the focal point of the study is a comparison of the changes by condition, for each of the growth parameters, intercept and slope were estimated. The coefficient for the control is represented by an intercept, and coefficients for each treatment condition (NF and CT) represent the difference in slope from the control. All models were estimated using HLM version 7.0 (Scientific Software International, Inc., Skokie, IL). All other analyses and data treatment were conducted using SYSTAT version 13.0 (Systat Software, a subsidiary of Cranes Software International Ltd., Bangalore, Karnataka, India). Following the objectives of the hypotheses, we consider this randomized control efficacy trial a superiority trial, as we are testing whether the CompAT interventions are superior to (not different from in either direction) community treatment alone and if NF is superior to CT, resulting in the application of 1-tailed tests.[48]

To examine stimulant medication changes, Cohen's *d* effect sizes were calculated, and paired *t* tests were conducted to analyze within group mean changes. An analysis of covariance was then performed to compare differences between conditions at postintervention while accounting for baseline differences.

RESULTS

Of the 104 participants who enrolled in the study (34 in the neurofeedback [NF] condition, 34 in the cognitive training [CT] condition, and 36 in the control condition), 102 completed the 40-session intervention (Fig. 1). The mean response rates for pre- and postintervention data were 94.0% for the primary parent, 76.6% for the secondary parent, and 99.0% for the teacher. The Behavioral Observation of Students in Schools (BOSS) was completed 3 times at each time point for 100% of participants, and interrater reliability remained high throughout all observations (mean $\kappa = .89$). At baseline, 95% of participants showed clinically significant scores ≥ 65 on the DSM-4 ADHD Inattention and/or Hyperactive/Impulsive subscales, and 49% of participants were on ADHD medication. There were no statistical differences between

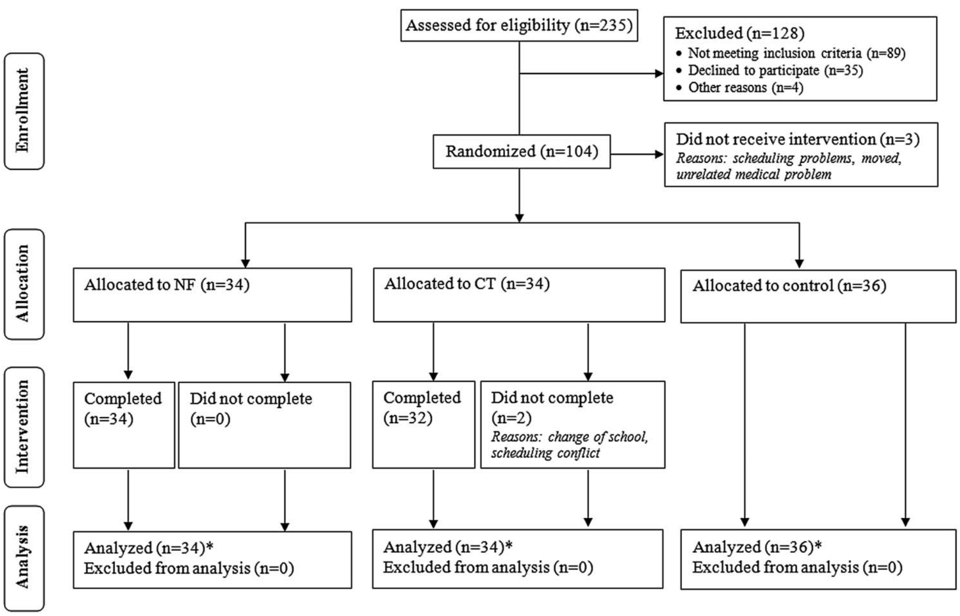

Figure 1. Consort diagram. *In a small number of cases, parent or teacher data were missing. Therefore, sample sizes may be somewhat smaller than is indicated. CT, cognitive training; NF, neurofeedback.

randomization conditions at baseline regarding gender, family income, race, medication use, or baseline ADHD symptom outcome measures (Table 1). There was no difference in symptom severity between children on and off ADHD medication at baseline on the Conners 3-P Global Index ($t(98) = -.75$; $p = .45$). There were no differences between participants who completed or did not complete the intervention. No adverse side effects of either intervention were reported on the standardized session checklists. Means and effect sizes for pre- and post-intervention are presented in Table 2.

In the growth model, the majority of distributions for the measures at each time point and the changes were roughly symmetrical and tailed, but normality could not be assumed for all scales, so we relied on the robust standard errors available in HLM in the assessment of hypotheses in Conners 3-P, Behavior Rating Inventory of Executive Function (BRIEF), Swanson, Kotkin, Agler, M-Flynn and Pelham scale (SKAMP), Conners 3-T, and BOSS models.

Parent-Reported Measures

Children in the NF condition showed significant improvements over time compared to the control condition on the Conners 3-P for Inattention ($p = .001$) and Executive Functioning ($p = .001$) study-targeted subscales, the Global Index ($p = .02$) (Table 2), and 3 out of the remaining 6 general subscales (Supplemental Digital Content, http://links.lww.com/JDBP/A54). Significant improvements for the NF condition were also found on the BRIEF Behavior Regulation ($p = .03$), Metacognition ($p = .04$), and Global Executive Composite ($p = .01$) summary scales (Table 2) and on 5 of the 8 subscales (Supplemental Digital Content, http://links.lww.com/JDBP/A54). No significant pre-post differences were found in the CT condition on any parent-reported outcome measures. Furthermore, children in the NF condition showed significant improvements over time compared to those in the CT condition on 4 of 11 Conners 3-P subscales (Table 2; Supplemental Digital Content, http://links.lww.com/JDBP/A54), and on 6 of 11 BRIEF subscales (Table 2, Supplemental Digital Content, http://links.lww.com/JDBP/A54).

Teacher-Reported Measures

Teachers reported improvements among children in the NF condition on the Attention subscale average (effect size [ES] = 0.34) and Total average (ES = 0.30) on the SKAMP and on the Inattention subscale of the Conner 3-T (ES = 0.25). Differences between the intervention conditions and the control condition did not reach statistical significance (Table 2; Supplemental Digital Content, http://links.lww.com/JDBP/A54); however, children in

Table 1. Participant Characteristics

	NF	CT	Control
N	34	34	36
Age, yr[a]	8.4 (1.1)	8.9 (1.0)	8.4 (1.1)
Male	23	22	25
Race			
White	23	24	29
Black or African American	3	1	3
Asian	7	8	4
Fourth grade[b]	21	28	22
Second grade	13	6	14
Family income $74,999 or less	13	12	12
Suburban school district	24	25	27
IQ composite[a]	106.6 (13.9)	108.4 (14.3)	108.9 (15.4)
Verbal IQ[a]	101.3 (16.7)	103.9 (19.4)	105.1 (16.3)
Nonverbal IQ[a]	109.6 (12.5)	110.2 (12.1)	109.7 (17.7)
ADHD medication	15	14	20
Medication MPH equivalent[a,c]	28.9 (14.4)	24.2 (10.2)	25.1 (15.9)
Counseling (private)	9	7	8
School services: IEP/504 plan	27	22	21
Conners 3-P Global Index[a]	75.8 (13.5)	70.9 (10.8)	74.6 (12.1)
BRIEF Global Executive Composite[a]	66.3 (10.0)	61.8 (6.6)	64.7 (9.0)
BOSS Engagement[a]	72.2 (12.4)	73.4 (13.3)	78.2 (11.7)
BOSS off-task motor/verbal[a]	30.2 (17.1)	25.9 (15.1)	21.1 (13.9)

[a]Mean (standard deviation). [b]Significant difference between the groups. [c]Only includes participants who were on a stimulant medication. ADHD, attention-deficit hyperactivity disorder; BOSS, Behavioral Observation of Students in Schools; BRIEF, Behavior Rating Inventory of Executive Function; CT, cognitive training; IEP, individualized education plan; IQ, intelligence quotient; MPH, methylphenidate; NF, neurofeedback.

Table 2. Observed Data and Growth Model Results

	Observed Data			Growth Model Estimates[a]				
	Preintervention Mean (SD)	Postintervention Mean (SD)	Effect Size[b]	Coefficient	Confidence Interval	NF vs Control	CT vs Control	NF vs CT
Conners 3-Parent								
Inattention								
Control	76.7 (10.0)	75.2 (10.5)	−0.15	−0.61	−2.55 to 1.32	—	—	—
NF	80.1 (10.8)	71.4 (10.8)	−0.80	−6.22	−8.94 to −3.50	***	—	—
CT	74.8 (9.5)	70.2 (10.3)	−0.46	−2.40	−6.51 to 1.71	—	—	—
Executive Functioning								
Control	69.3 (11.6)	70.5 (12.6)	0.09	1.14	−1.01 to 3.29	—	—	—
NF	72.2 (12.2)	66.0 (13.2)	−0.49	−6.72	−9.71 to −3.73	***	—	*
CT	67.5 (12.0)	66.0 (12.1)	−0.12	−3.08	−6.52 to 0.35	—	—	—
Global Index								
Control	74.6 (12.1)	74.0 (12.1)	−0.05	0.37	−1.74 to 2.49	—	—	—
NF	75.8 (13.5)	70.7 (13.7)	−0.37	−3.94	−7.07 to −0.80	*	—	—
CT	70.9 (10.8)	69.9 (12.4)	−0.09	−1.54	−5.24 to 2.15	—	—	—
BRIEF-Parent								
Behavior Regulation Index								
Control	60.8 (11.6)	61.4 (10.4)	0.05	−0.21	−2.34 to 1.92	—	—	—
NF	62.4 (11.5)	59.0 (10.1)	−0.32	−3.64	−6.62 to −0.65	*	—	*
CT	59.3 (8.7)	59.9 (10.3)	0.06	−0.11	−3.26 to 3.04	—	—	—
Metacognition Index								
Control	65.5 (8.4)	65.5 (9.5)	0.00	−0.85	−2.37 to 0.67	—	—	—
NF	66.9 (9.7)	62.8 (9.1)	−0.44	−2.70	−5.12 to −0.27	*	—	*
CT	62.1 (6.7)	61.3 (8.2)	−0.11	0.12	−2.24 to 2.49	—	—	—
Global Executive Composite								
Control	64.7 (9.0)	64.8 (9.0)	0.02	−0.75	−2.43 to 0.92	—	—	—
NF	66.3 (10.0)	62.1 (8.9)	−0.45	−3.19	−5.69 to −0.70	*	—	*
CT	61.8 (6.6)	61.5 (8.3)	−0.04	0.37	−2.22 to 2.96	—	—	—
SKAMP-Teacher								
Total								
Control	1.6 (0.8)	1.5 (0.6)	−0.14	−0.10	−0.25 to 0.05	—	—	—
NF	1.7 (0.7)	1.5 (0.8)	−0.30	−0.12	−0.34 to 0.10	—	—	—
CT	1.5 (0.8)	1.5 (0.7)	0.00	0.09	−0.13 to 0.30	—	—	—
Attention								
Control	1.9 (0.9)	1.8 (0.7)	−0.15	−0.12	−0.29 to 0.05	—	—	—
NF	1.9 (0.8)	1.6 (0.8)	−0.34	−0.17	−0.42 to 0.08	—	—	*
CT	1.7 (0.9)	1.7 (0.9)	−0.01	0.10	−0.13 to 0.33	—	—	—
Conners 3-Teacher								
Inattention								
Control	68.1 (10.4)	68.2 (10.6)	0.00	0.45	−2.05 to 2.95	—	—	—
NF	68.4 (11.7)	65.5 (11.6)	−0.25	−3.16	−6.79 to 0.48	—	—	*
CT	65.2 (10.6)	67.6 (9.0)	0.24	0.87	−2.12 to 3.85	—	—	—
BOSS-Classroom Observation								
Motor/verbal Off-task								
Control	21.1 (13.9)	18.4 (12.0)	−0.21	−2.70	−6.53 to 1.13	—	—	—
NF	30.2 (17.1)	20.8 (14.2)	−0.60	−6.65	−12.16 to −1.15	*	—	—

(*Table continues*)

Table 2. Continued

	Observed Data			Growth Model Estimates[a]				
	Preintervention Mean (SD)	Postintervention Mean (SD)	Effect Size[b]	Coefficient	Confidence Interval	NF vs Control	CT vs Control	NF vs CT
CT	25.9 (15.1)	20.0 (10.9)	−0.45	−3.46	−9.01 to 2.09	—	—	—
Total Engagement								
Control	78.2 (11.7)	79.3 (13.6)	0.09	1.14	−2.98 to 5.25	—	—	—
NF	72.1 (12.4)	78.0 (14.6)	0.43	4.68	−1.22 to 10.59	—	—	—
CT	73.4 (13.3)	77.1 (13.6)	0.28	2.56	−3.41 to 8.53	—	—	—

*$p < .05$, **$p < .01$, ***$p < .001$. [a]The growth model estimates a coefficient representing a change in the slope between the intervention conditions and the control condition over the two time points. A post hoc analysis was conducted to determine differences between the NF and CT slopes over the 2 time points. [b]Effect size is between pre- and postintervention. BOSS, Behavioral Observation of Students in Schools; BRIEF, Behavior Rating Inventory of Executive Function; CT, cognitive training; NF, neurofeedback; SKAMP, Swanson, Kotkin, Agler, M-Flynn and Pelham scale.

the NF condition showed significant improvements over time compared to the CT condition on the SKAMP Attention subscale average (p = .03) and the Conners 3-T Inattention subscale (p = .02; Table 2).

Classroom Observation

On the BOSS, NF, CT, and control conditions, all showed statistically significant changes over time in off-task motor/verbal. Children in the NF condition showed significantly greater improvement than those in the control condition (p = .02) on this scale. Furthermore, children in the NF condition showed improvements in engaged behavior (ES = 0.43), although these differences were not statistically significant compared to those in the control condition. Differences between CT and the control condition and between NF and CT did not reach statistical significance (Table 2; Supplemental Digital Content, http://links.lww.com/JDBP/A54).

Stimulant Medication

Among participants receiving stimulant medication at preintervention and/or postintervention (n = 58), parents reported significantly increased stimulant medication dosage, measured in methylphenidate (MPH) equivalents, in both control and CT conditions (7.05 mg and 8.54 mg, respectively; both $p < .05$). Parents of children in the NF condition reported a minimal mean increase (0.29 mg; p = .47). No between-group dosage differences were found ($F(2) = 1.29$; p = .14).

When analyzing only the subgroup of participants on medication, findings follow the same trend (i.e., children who received NF improved significantly; however, children who received CT or who were in the control condition did not). Furthermore, when comparing participants on stimulant medication versus off–stimulant medication, NF participants improved in both cases. The only difference between NF participants' improvement whether on or off mediation was on the BRIEF Global Executive Composite, where children taking medication made greater improvements than those not taking medication ($t(28) = 2.12$; p = .04). Stimulant medication status did not alter the outcome for children in CT or control conditions, which both showed no statistical improvements on or off medication.

DISCUSSION

Parents, teachers, and observers reported significant improvements in attention-deficit hyperactivity disorder (ADHD) symptoms among children receiving the neurofeedback (NF) intervention. Stimulant medication dosage was not changed among children in the NF condition. Reporters did not note significant improvements among children in the cognitive training (CT) condition compared to the control or NF conditions, and stimulant medication dosage had significantly increased over the study period.

These outcomes support the efficacy of NF. Our results are similar to those in a previous study that analyzed NF versus CT.[27] The parent-reported improvements of participants in the NF condition on the learning problems subscale might reflect important generalization of skills to the academic setting. Furthermore, it is noteworthy that parents of children in the NF condition did not seek an increase in their children's stimulant medication dosage, although these children experienced the same physical growth and increased school demands as their CT and control peers.

It is interesting that we did not find improvements in children who received the CT intervention compared to the control condition, as we had hypothesized. This could be because CT trains specific areas that might not be so readily generalized to other areas of functioning. On the other hand, NF aims to alter brainwave activity through cortical self-regulation, where students learn how it "feels" to think in a focused manner, which might lead to increased generalization outside of the sessions.

Goals of ADHD interventions are complex, and it is challenging to accurately capture change that impacts function. For instance, an ADHD intervention might be successful at improving 1 targeted ADHD symptom, which significantly improves the daily functioning of a child. Yet, questionnaires might not reflect this specific improvement. Our results show that participants on medication presented at baseline with the same level of ADHD impairment as those who were not taking medications. This could be interpreted in several ways. First, that medication does not have an effect, which seems unlikely. Second, that before starting medication, participants showed more severe symptoms than those not taking medication, but that their medication dosage was only titrated to reach improvement toward an acceptable level of function, yet not normalizing it. Finally, that normalization could not be achieved through medication alone. Furthermore, the finding that children on stimulant medication improved to the same magnitude as those not on stimulant medication suggests that stimulant medication does not hamper the therapeutic effect of NF. This is clinically an important factor regarding NF attention training and has been debated in previous works, and it means that NF is accessible as a stand-alone therapy option or an adjunctive treatment to medication. The degree of improvement found in the NF condition represents an important increase in functionality in elementary school–aged participants. This is the first randomized control efficacy trial of NF that has been done in schools, and despite expected implementation challenges, the implementation of the protocol was feasible.

Limitations

Although many research studies use more rigorous, independent standards for inclusion to confirm participant ADHD diagnosis, we believe that using clinician reports was justified for several reasons. First, we found that 95% of children fell in the clinical range according to parents' reports on the Conners 3-P DSM-4 ADHD Inattention and/or Hyperactive/Impulsive subscales at baseline, regardless of whether the participant was on medication. Second, evidence suggests that children with subdiagnostic levels of ADHD symptoms often experience significant impairment and benefit from treatment.[49,50]

Both children and parents were aware of the child's intervention condition because we believed that parents would not tolerate being uninformed. However, every effort was made to limit parent bias (see Interventions). We found no differences in satisfaction with the intervention between parents in the NF condition and those in the CT condition, which suggests that parents were not biased regarding the treatment type. Although a sham treatment might be considered in a laboratory setting, a sham arm of the protocol was not deemed acceptable within the school setting by principals and the teaching staff, already concerned with lost classroom time for participants to receive a potentially effective intervention (i.e., NF and CT). Thus, the control condition was the most reasonable solution.

Although the projected sample size based on the power analysis was not achieved, moderate-sized effects were still found. Furthermore, the study was not powered to test for moderating and mediating hypotheses. We did not have data on the type of learning disability identified on the participants' individualized education plans or 504 plans. In future studies, with larger sample sizes, it would be valuable to look at the moderating effect of various learning disabilities on treatment. The diagnosis of ADHD occurs throughout childhood, which explains why there were significantly more fourth graders than second graders enrolled in the study.

CONCLUSIONS

Parents of children who received neurofeedback (NF) training reported significant improvements in attention and executive functioning, showing that this intervention holds promise as a treatment intervention for children with attention-deficit hyperactivity disorder (ADHD). Parents of children who received cognitive training (CT) did not report significant improvements compared to those in the control condition. As parents were explicitly advised to continue community treatments based on their physician's recommendations and the child's best interest, the finding that children in the NF condition maintained the same medication dosage while those in both of the other conditions increased dosage supports the efficacy of NF above and beyond community treatments. These data support the feasibility of computer attention training (CompAT) systems and the efficacy of NF delivered in a real-world school setting. Public school systems are very concerned with supporting students' attention and improved learning, and many are currently using CompAT systems, despite the absence of systematic guidelines or efficacy data. Schools remain the prime location for such an intervention because of the direct impact of attention deficits on academic progress and also because school delivery allows for equal access to all children in all communities on an ongoing, consistent basis.

As the implementation process was somewhat labor intensive with a 2:1 student-to-research assistants ratio, future studies should consider conducting sessions with larger student-to-staff ratios to increase the feasibility of implementation on a larger scale. Future research should assess (1) evidence of maintained benefit of CompAT interventions in the school setting after a time lapse and (2) analysis of moderating factors that might influence successful intervention and suggest mechanisms for individualization of attention training systems.

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