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Aim and Scope

NeuroRegulation is a peer-reviewed journal providing an integrated, multidisciplinary perspective on clinically relevant research, treatment, and public policy for neurofeedback, neuroregulation, and neurotherapy. The journal reviews important findings in clinical neurotherapy, biofeedback, and electroencephalography for use in assessing baselines and outcomes of various procedures. The journal draws from expertise inside and outside of the International Society for Neurofeedback and Research to deliver material which integrates the diverse aspects of the field. Instructions for submissions and Author Guidelines can be found on the journal website (http://www.neuroregulation.org).

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Editorial – Volume 3, Number 2

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Greetings and welcome to *NeuroRegulation* Volume 3, Number 2. Neurofeedback continues to gain both positive and negative attention from other disciplines as well as the public sector. Nonetheless neurofeedback continues to progress in its technology and applications. In the current issue, data is presented for such applications. First, Drs. Jeffry La Marca and Rollanda O'Connor discuss interesting results for neurofeedback in the educational setting for students with the inattentive subtype of Attention-Deficit/Hyperactivity Disorder. Second, Drs. Alison Walker and Randall Lyle present data for the treatment of nonaura migraines using Passive Infared Hemoencephalography (pIR HEG) in a group of adult clients. Finally, Mr. Robert Longo and Dr. David Helfand present data for a case study of neurofeedback for cognitive and affective difficulties associated with chemotherapy.

We thank the authors for contributing their work to *NeuroRegulation* and encourage other clinicians and researchers to contribute. It is important to increase the awareness of neurofeedback, its scientific merit, and its success in alleviating problems associated with various difficulties. We are seeking case studies for such applications. Consider publishing your next case study or research article with *NeuroRegulation*.

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Neurofeedback as an Intervention to Improve Reading Achievement in Students with Attention-Deficit/Hyperactivity Disorder, Inattentive Subtype

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Abstract

Research consistently demonstrates that attention deficits have a deleterious effect on academic achievement. Impairments in attention, and not hyperactivity/impulsivity, are associated with learning difficulties and academic problems in students with attention-deficit/hyperactivity disorder (ADHD). To date, most studies have focused on symptoms of hyperactivity/impulsivity, with little research being conducted on interventions for students with ADHD, inattentive subtype. This study examines the use of neurofeedback as an intervention to improve reading achievement in a public school setting. A multiple-baseline-across-participants single-case model was used to assess five fourth-grade students who received 40 daily sessions of neurofeedback. Following the intervention, improvements were observed on objective measures of attention: a continuous performance test (Integrated Visual and Auditory Continuous Performance Test [IVA+Plus]) and/or a test of shifting attention (CNS Vital Signs, Shifting Attention Test [CNS-VS, SAT]). Results on tests of reading fluency revealed little change, although participants demonstrated gains on a measure of reading comprehension (Gray Oral Reading Tests–Fifth Edition [GORT-5]). Results suggest that neurofeedback helped participants to become more accurately engaged with the text with more focused attention to content. Thus, neurofeedback may be a viable option to assist children with attention deficits for improving both attention and reading achievement.

Keywords: academic achievement; attention deficit; interventions; neurofeedback; public schools; reading comprehension

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Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is considered to be among the most widely studied and treated of all psychiatric disorders (American Academy of Pediatrics, 2011; Goldman, Genel, Bezman, & Slanetz, 1998; Hart, Lahey, Loeber, Applegate, & Frick, 1995; Volkow et al., 2011). It is a heterogeneous condition characterized by the presence of a variety of symptoms, the most salient of which includes problems with inattention, executive function, impulsivity, memory, and hyperactivity (American Psychiatric Association, 1994). The fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) recognizes a single disorder that consists of three subtypes: the predominately hyperactive-impulsive subtype, the predominantly inattentive subtype, and the combined subtype where individuals meet criteria for both hyperactivity/impulsivity and inattention (American Psychiatric Association, 2000).

The National Center for Health Statistics reported that 9.0% of children (12.3% of boys and 5.5% of girls) between the ages of 5 and 17 have been diagnosed with ADHD (Akinbami, Liu, Pastor, &

Reuben, 2011). Froehlich et al. (2007) examined prevalence by subtype and found that the majority of students with ADHD meet criteria for the inattentive subtype (51%), followed by the combined subtype (26%), and then the hyperactive/impulsive subtype (23%).

The combined subtype predominates in the literature as the focus of study (Dige, Maahr, & Backenroth-Ohsako, 2008; Nigg, 2005), with sparse research focusing solely on the hyperactive/impulsive subtype in isolation from symptoms of inattention. Likewise, the inattentive subtype (i.e., attention-deficit/hyperactivity disorder without hyperactivity) received little attention until the early 1990s when it was recognized by the American Psychiatric Association (1994).

Although the construct of ADHD has been developed through a medical model, the impact that attention deficits have on students' learning has been studied since the first clinical observations on the topic (American Academy of Pediatrics, 2011; Crichton, 1798; Still, 1902a, 1902b, 1902c). Despite reliance on this medical model to classify attention deficits, addressing the needs of students with ADHD is especially critical in schools, because school is where most children are first identified and their impairments become evident (U.S. Department of Education, Office of Special Education and Rehabilitative Services, & Office of Special Education Programs, 2008). Research consistently demonstrates that attention deficits have a deleterious effect on academic attainment (Barkley, 2002). Although medical and psychological interventions may be useful, the responsibility for accommodating students with special needs in school ultimately falls to educators.

Attention and Reading Achievement

Research has indicated that children with ADHD, inattentive subtype, have considerably slower rates of processing speed than both typically developing peers and students with other subtypes (Chhabildas, Pennington, & Willcutt, 2001; Ghelani, Sidhu, Jain, & Tannock, 2004). In particular, individuals with the inattentive subtype process visual information slowly and exhibit impairments in allocating attention to information within their visual field (Barkley, Grodzinsky, & DuPaul, 1992; Swanson, Posner, Potkin, & Bonforte, 1991). Reading and math disorders, along with other learning disabilities, appear to be more prevalent in individuals with the inattentive subtype than with the predominately hyperactive-impulsive type (Barkley et al., 1992; Bauermeister, Alegría, Bird, Rubio-Stipec, & Canino, 1992; Willcutt & Pennington, 2000).

Ghelani et al. (2004) noted that reading disabilities (RD) and ADHD frequently overlap, and yet few studies specifically address ADHD and reading comprehension. They examined reading rate and comprehension of 96 adolescents, ages 14 to 17 across four groups: students with ADHD only (n = 32), RD only (n = 20), ADHD and RD (ADHD/RD; n = 19), or a control group (n = 25) of typical readers. Study participants were then administered a variety of reading tests. Analysis revealed that all ADHD and/or RD groups scored lower on silent reading comprehension than the control group, and both the RD and ADHD/RD groups scored significantly lower than controls on tests of reading rate and accuracy. The performance of the comorbid ADHD/RD group on tests of reading accuracy and rate was similar to that of the RD group. On reading comprehension, students with ADHD/RD did poorly with silent reading but not with oral reading. These results are similar to another study (Schuck, 2008) that also found that students with ADHD faced difficulties when reading silently, but not orally.

Weiler, Bernstein, Bellinger, and Waber (2000) examined processing speed in children with ADHD, inattentive subtype. Participants included 82 children between the ages of 7 and 11 who met criteria for the inattentive subtype and/or were identified as RD: children with either the hyperactive-impulsive or combined subtypes were excluded. Additional children were excluded during the screening process if their full-scale IQ was less than 80, they were taking stimulant medications, or presented with behavioral or emotional problems. Study participants were then subdivided into four groups: ADHD inattentive subtype without RD (ADHD/non-RD), ADHD inattentive subtype with RD (ADHD/RD), RD only, or a fourth group that did not have ADHD or RD. Participants were then administered a battery of timed tests. Findings revealed that while all participants performed less than expected on tasks that measured processing speed, children with ADHD, inattentive subtypes, were significantly slower than the groups without ADHD. Statistically significant differences were found between the ADHD/RD and non-ADHD/RD group when compared on tasks of processing speed, written language, and a test of motor speed: the ADHD/RD group did worse on these tasks.

Neurofeedback and reading achievement. The literature has long noted that neurofeedback produces positive outcomes on a variety of cognitive

and academic measures (Leins et al., 2007; Linden, Habib, & Radojevic, 1996; Vernon et al., 2003); however, most neurofeedback studies have been conducted in clinical settings, while few studies have been conducted in K–12 schools. We wished to examine the effects of neurofeedback, particularly improvements in attention, in a public school setting. Moreover, for improvement in attention to matter, it should affect domains known to be important to school achievement. Using the findings of studies that demonstrated deficits in processing speed for visual stimuli (Barkley et al., 1992; Swanson et al., 1991) and reading comprehension (Ghelani et al., 2004) for students with ADHD, we selected reading skills as our academic outcome for neurofeedback training. Moreover, reading serves as the foundation on which many other content areas are built; thus improvements in both attention and reading ability, if found, would establish social validity for the process. Therefore, the intent of our research is to explore the feasibility of an intervention in an elementary school setting, as well as examine if improvement in attention, resulting from neurofeedback translates into gains in academic achievement, thus addressing the most salient concern of educators to maximize opportunities for learning.

At present, only a handful of neurofeedback studies have been conducted in public schools. Wadhwani, Radvanski, and Carmody (1998) published a case study of a middle school student with ADHD and noted improvements on a standardized achievement test. The same research team (Carmody, Radvanski, Wadhwani, Sabo, & Vergara, 2001) conducted a study in an elementary school of students who exhibited behavioral problems and ADHD; however, their results were inconclusive. Orlando and Rivera (2004) examined the use of neurofeedback to improve reading performance. Their sample included 34 public school students with ADHD in grades six, seven, and eight, with three additional students from a different school in grades one, four, and five. The authors acknowledged the disparity in age of their participants and potential issues concerning the heterogeneity of their sample. Some participants purportedly had "identified learning problems," but these impairments were not identified. Attrition rates were high and standardized procedures were not established for pre- and post-assessments. Of the 17 students in the original experimental group, only 12 completed the study. Of those, nine participants' treatment protocols were based on quantitative electroencephalographic (qEEG) evaluations conducted by a volunteer neurofeedback practitioner from the local community; these were used as a "protocol guide" by the primary author. The three remaining students were not assessed with qEEGs and "protocols were developed based upon the clinical decisions made by the psychologist and upon information gained from teachers and/or parents concerning the student's behavior for the week" (Orlando & Rivera, 2004, p. 6). Screening procedures also failed to control for comorbid conditions with one participant being jailed just as the study commenced and another reclassified as "mildly mentally retarded." Although the authors concluded that neurofeedback was more effective than no training for improving reading achievement, lack of experimental control draws this finding into question.

Steiner, Frenette, Rene, Brennan, and Perrin (2014) reported a randomized controlled trial in a public school setting that neurofeedback training improved symptoms of inattention and holds promise as an intervention. However, the researchers only used subjective outcome measures including parent and teacher rating scales of attention and behavior and classroom observations. The study did not report on any measures of academic achievement.

Coben, Wright, Decker, and Morgan (2015) reported that coherence-based neurofeedback resulted in "significant gains in reading" following 20 sessions. However, they did not specify what components of the reading process improved (e.g., accuracy, comprehension, fluency, word attack). They noted that all study participants (n = 42) "received pre- and post-educational measures focused on reading abilities" that included the administration of the Woodcock-Johnson Tests of Achievement III (WJ III; Woodcock, McGrew, & Mather, 2007) and the Gray Oral Reading Tests–Fourth Edition (GORT-4; Wiederholt & Bryant, 2001). However, an issue arises concerning the use of the GORT-4, which has been found to lack both content validity and concurrent validity as a measure of reading comprehension. Keenan and Betjemann (2006) reported that reading comprehension on the GORT-4, using multiple-choice questions that are answered following the reading of graded stories, were not passage-independent. In other words, it is possible to answer many of the questions without having read each passage.

Given the limited research on neurofeedback and academic achievement, we decided to examine its effects in a public school setting. Furthermore, a dearth of research exists in schools even though school is where neurofeedback, arguably, has the potential to have the greatest impact. Our intent

was to examine what effects, if any, neurofeedback may have on attention and reading achievement.

Our research examined three research questions within the context of examining the efficacy of neurofeedback with students presenting with symptoms of ADHD, inattentive subtype, in a public school setting:

1) Will neurofeedback enhance attention as measured by Continuous Performance Tests (CPTs)?
2) Will neurofeedback improve performance on measures of reading fluency?
3) Will neurofeedback improve performance on measures of reading comprehension?

Method

Participants

Participants were selected from students in a relatively affluent suburban coastal community in southern California at an elementary school. In keeping with the requirements of the University of California, Riverside's Human Research Review Board (HRRB), all students had to be referred by school officials. Specifically, the HRRB required that the school psychologist and administrators identify potential candidates (blind to the researcher) for screening based on reviews of educational records. Students with educational histories in which ongoing problems with inattention and distractibility had been noted by current or former teachers and parents, as well as candidates with confirmed medical diagnoses of ADHD, inattentive type, were to be considered. Once a pool of potential candidates was selected, we were able to screen for participants who met inclusionary criteria.

Description of setting. Participants were students in general education classrooms at the Sunny Shoals Elementary School, one of many schools within the large Maritime Unified School District (the name of the school and school district are pseudonymous). The school is located in a relatively affluent suburban coastal community of southern California. During the 2012/2013 school year, 611 students in grades K to 5 were served by 18 general education classroom teachers and four special education teachers.

As the intent of this study was to examine the use of neurofeedback in a school setting, a space within a special education classroom at Sunny Shoals Elementary School was provided for our research. The classroom was used throughout the day by small groups of students who were pulled out of general education classrooms in order to receive specialized instruction. A dedicated place, segregated from the rest of the classroom, was provided at the back of the room for the latter half of the school year so that all aspects of this study could be conducted during the school day without interruption. The only exception occurred to conduct qEEG assessments. While these were also conducted during the school day, a separate room was used.

Participant selection process. The participant selection process consisted of two phases; an initial phase where a pool of potential participants was identified and administered several instruments designed to determine if they might be appropriate candidates for the study, and a second phase during which participants were exposed to neurofeedback and confirmed final eligibility based on the study's criteria. All assessments throughout the study were conducted at the school site, during regular school hours. The initial target group included 15 students in Grades 3–5, as children of this age have received several years of reading instruction and passed the age-of-onset criterion for ADHD as established by the DSM-IV-TR (APA, 2000). Potential participants who did not meet criteria for ADHD and those with profiles indicative of either the ADHD hyperactive or combined subtypes were excluded.

Once the initial pool of 15 potential candidates had been identified, the school provided each student's parents with an information letter and consent form. The parents of 10 students returned signed consents; one student was in third grade, eight students in fourth, and one in fifth, all between nine and 10 years of age. Following initial screening, three participants (two in fourth grade and one in fifth) did not meet the study's criteria and were excluded. This left seven students to continue with the final phase of screening. A second set of letters and consent forms were sent to the parents of these students, and student participants were asked to sign an assent form. One student's parents declined to give consent, and the third grade student became anxious immediately prior to the beginning of the final assessment (a qEEG evaluation) and withdrew from the study. Of the five students remaining, all completed screening procedures and participated in the study. These five participants included an ethnically diverse group of students consisting of four boys and one girl, all between the ages of nine and 10 (Table 1; the names of all participants are pseudonymous).

Table 1

Participant Demographics

Student	Age	Gender	Grade	Ethnicity	Existing Diagnosis	Family History ADHD	Prescription Medications	Referred for IEP/504	Eligible for Services	Teacher Referral
Mildred	9.58	F	4	Hispanic	No	Yes	No	No	No	Yes
Dudley	10.63	M	4	Black	Yes	No	No	504	Yes	Yes
Nimrod	9.37	M	4	Vietnamese	No	No	No	No	No	Yes
Webster	10.66	M	4	White	No	Yes	No	No	No	Yes
Egbert	9.98	M	4	Hispanic	Yes	No	No	IEP	No	Yes

Note. Age calculated at the time of the study.

Selection criteria. In addition to the age/grade, consents, expressed interest, and school attendance requirements, students selected for the study met the following inclusionary criteria:

1) Ratings by a parent and/or a teacher on an ADHD rating scale that exceeding the cutoff for an attention deficit (T-scores ≥ 61 on the Conners 3ADHD Index, Parent and Teacher Rating Scales, described below),
2) Demonstrated impaired performance on a CPT that was consistent with ADHD (determined by proprietary algorithms used by the IVA+Plus, described below),
3) A full-scale intelligence quotient (FSIQ) ≥ 80, and
4) Theta/beta ratios ≥ 2.0 (theta = 4 to 8 Hz, beta = 15 to 18 Hz) at Cz.

The presence of comorbid conditions (e.g., seizure activity, brain injury, psychiatric conditions such as anxiety, depression, or other brain-based impairments) would have resulted in exclusion from participation; however, no potential candidates were excluded for these reasons.

Neurofeedback software and equipment.

Neurofeedback system. SmartMind Pro (Sandford, 2012), consisting of an EEG software application and a two-channel EEG amplifier, was used to provide neurofeedback to students. The software ran on a laptop computer using Microsoft's Windows 7 operating system that was connected to the amplifier. EEG was measured using gold-plated disk recording electrodes and ear clips.

The neurofeedback software displays each participant's EEG in real time with output customizable to show only the bandwidths selected for training. Neurofeedback is accomplished using specially designed computer games. Although some of the neurofeedback games require the use of a mouse, only those that used EEG were implemented to avoid variability that might be attributed to operating the computer through physical activity. The software records and maintains information about each activity within a session; these data include the mean amplitude of EEG bandwidths being trained in Hz, standard deviation of each frequency band, and session time.

The neurofeedback system was used during the final stage of screening to identify potential participants with elevated theta/beta ratios. Studies have shown that higher ratios are particularly observable over the frontal and central midline brain regions. Previous research has suggested that elevated ratios are an electrophysiological indicator found in EEGs of individuals with ADHD (Monastra et al., 2005; Snyder & Hall, 2006). Research has reported that the individuals with ADHD who benefit most from neurofeedback are those with elevated theta/beta ratios (Monastra, Monastra, & George, 2002).

qEEG software and equipment. The qEEG assessments were conducted using WinEEG software developed by Mitsar Co. Ltd. (Saint Petersburg, Russia). Data were collected with a 21-channel Mitsar EEG-201 amplifier. Similar to the equipment used with the neurofeedback system, gold-plated disk EEG recording electrodes and ear clips were at all 19 standardized scalp locations established by the International 10/20 System (Jasper, 1958). Following each assessment data were compared with the Human Brain Institute (Saint Petersburg, Russia) normative database.

Measures

Screening measures. Participant selection was based on criteria that identified students with profiles consistent with the definition of ADHD, as defined by the DSM-IV-TR. Children with an existing diagnosis (made by a qualified medical professional) of ADHD, Inattentive Subtype, were considered for inclusion. As there are no "gold standards" for the identification of children with attention deficits, several measures were used for participant selection.

Student health history. Parents completed a student health history questionnaire, which included medical history and checked for an existing diagnosis of ADHD. Students diagnosed with the inattentive subtype were considered and those diagnosed with either the hyperactive/impulsive or combined subtypes were excluded. Two participants had been previously diagnosed with ADHD, and two additional students had parents indicate a family history of the disorder.

Parents of participants were asked at the onset of the study to disclose if their child was receiving pharmaceutical interventions. Potential participants were excluded from the screening process if they received pharmaceutical or other independent medical interventions for ADHD, especially if they received psychotropic medications (i.e., stimulant or other prescription medications). In the event that participants began medical interventions during the study, parents were asked to disclose this information because modifications, changes, and titrations of medications could affect progress monitoring and the results on outcome measures.

School records. Additional data were gathered on whether each student had been referred by a teacher for possible participation in special education programs, had been recommended for an Individualized Educational Program (IEP), or a plan under Section 504 of the Rehabilitation Action of 1973 (Section 504), and had been found eligible for services. Although all students had received teacher referrals for special education services, only two had been recommended for IEP/Section 504 plans, and just one had been found eligible. All teachers reported that referred students had problems with attention in the classroom environment. None of the participants received specialized reading instruction.

Rating scale. The Conners 3 ADHD Index (Conners 3AI; Conners, 2008a) is a screening instrument designed to differentiate ADHD children, ages 6 to 18, from typically developing peers and requires approximately five minutes to administer. There are separate forms for parents (Conners 3AI-P) and teachers (Conners 3AI-T); both contain 10 questions. T-scores ≥ 61 suggest responses describing children with ADHD (Conners & Research and Development Department, 2009). Participants were considered for inclusion if scores from either a parent or a teacher exceeded a T-score of 61. The ranges of internal reliability on the subtests for ages 6 to 9 are from .91 to .94. Test–retest reliability ranged from .84 to .93. The inter-rater reliability coefficient between parent and teacher forms is .85. The sensitivity of the 3AI-P is 88% and the 3AI-T is 79% (Conners, 2008b). For this study, if there was a discrepancy between raters and just one rater (parent or teacher) indicated that a potential participant's score exceeded the cutoff, screening continued with other measures to determine if the student's profile was congruent with a diagnosis of ADHD.

Continuous performance test. The Integrated Visual and Auditory Continuous Performance Test (IVA+Plus; Sandford & Turner, 2007) is a 13-minute CPT that uses both visual and auditory prompts to provide an objective measure of behaviors that are associated with the core symptoms of ADHD. A study of the IVA+Plus' validity reveals a sensitivity of 92%, specificity of 90%, and a concurrent validity with other diagnostic instruments (Test of Variables of Attention CPT [TOVA], the Conners Abbreviated Symptom Questionnaire, and the Conners Rating Scales) ranging from 90% to 100% (Sandford & Turner, 2009). Test–retest reliability has a range of .66 to .75 for Attention Quotient scores (AQ; inattention) and .37 to .41 for Response Control Quotient scores (RCQ; hyperactivity/impulsivity). Concurrent validity with other CPTs including the TOVA is 0.9. Potential participants with scores that indicated an attention deficit were considered for the study; proprietary algorithms used by the IVA+Plus Interpretive Flowchart that suggested a diagnosis of ADHD were used as one component of the participant selection process. Test results generate a Combined Sustained Attention (C-SA) score derived from Auditory Sustained Attention (A-SA) and Visual Sustained Attention (V-SA).

Intelligence screening. The Wechsler Abbreviated Scale of Intelligence–Second Edition (WASI-II; Wechsler, 2011) is a 15-min intelligence test for individuals ages 6 to 90 that provides estimates of Verbal IQ (VIQ), Performance IQ (PIQ), and FSIQ. For children ages 8 to 9, split-half reliabilities range from .85 to .91 for the subtests and .90 to .96 for the IQ scores. Concurrent validity with the WISC-IV,

have correlations ranging from .73 to .83 on the subtests and .79 to .91 for the IQ scores. A FSIQ ≥ 80 was used as a criterion for participants to be included in this study. All participants met criteria for FSIQ, with IQ estimates ranging from 90 to 107.

Screening for comorbid reading disabilities. The Woodcock Reading Mastery Test, Third Edition (WRMT-III; Woodcock, 2011) was used as a screening device to assess for the possibility of comorbid reading disabilities and as a measure of reading achievement. Results from the WRMT-III indicated that participants' Total Reading (standard) scores, derived from the Basic Skills and Reading Comprehension cluster scores ranged from 84 to 112. Oral Reading Fluency standard scores ranged from 85 to 100. One student, Webster, obtained high scores on several of the WRMT-III subtests and had a Reading Comprehension cluster score of 124. His Oral Reading Fluency score, however, was 96. Although Webster appeared to be a good reader, this study's exclusionary criteria did not address ceilings on screening instruments and, as this participant met criteria on all other measures, he was retained as a participant.

Baseline and outcome measures.

Measure of reading achievement. The Gray Oral Reading Tests–Fifth Edition (GORT-5; Wiederholt & Bryant, 2012a) is a standardized norm-referenced test of oral reading skills that provides measures of rate, accuracy, fluency, and comprehension. Students are presented with a series of passages that increase in difficulty. Rate and accuracy are scaled scores (scaled from 1 to 20 with a mean of 10 and a *SD* = 3) derived from the speed with which each passage is read in seconds and the number of words read correctly, respectively. The fluency score is derived from the rate and accuracy scores. Comprehension is a scaled score derived from correct responses to open-ended passage-dependent questions. An Oral Reading Index (ORI) provides a composite score derived from the fluency and comprehension scores.

The GORT-5 has two alternate forms; both forms require approximately 15 to 45 minutes to administer (Wiederholt & Bryant, 2012b). The reliability coefficients for the subtest scores on each form exceed > .85; the ORI coefficient on each from is .96 and .97, respectively. Test–retest reliability is .82 to .90. When one form was administered, followed by the alternate form, the test–retest reliability is .77 to .88 (Hall & Tannebaum, 2013; Wiederholt & Bryant, 2012b). In order to minimize potential issues with practice effect, Form 1 was used at pretest, Form 2 was used at posttest, and Form 1 was again used at follow-up.

qEEG assessment. qEEG assessments provide high temporal resolution of EEG activity and deliver low resolution "maps" of brain function. Chabot and Serfontein (1996) noted that qEEGs have a specificity of 88.8% and a sensitivity of 93.7% in distinguishing children with ADHD from typically developing others. Thus, qEEGs have diagnostic utility as part of the process for identifying children with ADHD. As these assessments must be conducted by qualified professionals and require considerable expertise to interpret; only the final set of candidates being considered as participants were evaluated. These qEEGs were also used as a baseline measure. Data obtained from the qEEG assessments were considered when developing the neurofeedback training protocols that addressed the unique EEG profiles of each participant.

qEEG evaluations were the last assessments to be done. For this procedure, electrodes were placed on participants at each of the 19 locations on the scalp with linked-ear reference. Interpretations of qEEG results were evaluated by a third-party expert in qEEGs and a medical doctor (both from Brain Science International, San Ramon, California), and then approved by a clinical psychologist who is an expert in qEEG evaluations and the use of neurofeedback for the treatment of ADHD. Individualized protocols were developed for each participant with the intent to maximize the efficacy of the neurofeedback training. Following completion of the study, qEEGs were again administered to each participant and pre- and post-intervention results were compared.

Progress monitoring measures. Participants had their progress monitored throughout the study on measures of attention, reading comprehension, and reading fluency. Specifically, following completion of each 30-min neurofeedback session, participants were administered three instruments, described below.

CNS Vital Signs (CNS-VS; Gualtieri & Johnson, 2006) is a battery of computerized neurocognitive tests (CNT) that includes a Shifting Attention Test (SAT), which measures attention during progress monitoring and also provides a measure of executive function that may indicate the presence of an attention deficit (Gualtieri & Johnson, 2006). Scores are provided for correct responses, number of errors, and correct reaction time in milliseconds. The test–retest reliability of the SAT for ages 7 to 90

(based on a normative sample, *n* = 99) with a median interval of 27 days ranges from .69 to .80 (Gualtieri & Johnson, 2006).

The Dynamic Indicators of Basic Early Literacy Skills (DIBELS; Good & Kaminski, 2003) test of Oral Reading Fluency (ORF) is a standardized measure of reading rate and accuracy. This task requires students to read aloud for 1 min from graded passages. Scores are calculated based on the total number of words read per minute minus the number of errors. Alternate form reliability is .92, test–retest reliability is .92 to .97, and concurrent validity with other tests is .80 (Shanahan, 2005). There are 30 DIBELS ORF reading passages available from the publisher. As the number of probes required for the study exceeded those available, two editions of the ORF were used (each contained a different set of 30 passages) with passages from each alternated every other session. All participants received fourth-grade passages with the exception of Webster, who received the eighth-grade set. Participants were asked to read for 1 min and their results recorded. Four participants were monitored using fourth-grade passages presented in the same order, while Webster received eighth-grade passages as his reading abilities were above grade level.

The AIMSweb Reading Curriculum-Based Measurement (R-CBM) Maze (Maze; Shinn & Shinn, 2002a) is a multiple-choice cloze task intended to serve as a measure of reading comprehension. The Maze requires participants to read silently for 3 min. The first sentence is complete. Every 7th word after that is replaced with a set of three words of which only one is correct. Participants are asked to select the correct word; correct and incorrect responses are counted to obtain raw scores (Shinn & Shinn, 2002b). Validity coefficients range from 0.60 to 0.80 (Shinn & Shinn, 2002a). The test–retest reliability for Grades 1–7 has a range of .66 to .91 (National Center on Response to Intervention, 2012). There are 24 Maze passages available from the publisher but the number of probes required during the study exceeded 40; these included the sessions required to establish baseline. To address this issue, the 24 passages were presented in sequence. They were then randomly reordered and repeated. Four participants were presented with the same fourth-grade passages in the same order; Webster received eighth-grade passages.

Procedures

Research design. Studies using single-case design (SCD) have been of considerable utility in the development of evidence-based practices in special education (Horner et al., 2005; Kennedy, 2005; Kratochwill et al., 2010), applied and clinical psychology (Chambless & Hollon, 1998; Gustafson, Nassar, & Waddell, 2011), and within the field of neurofeedback (Kratochwill et al., 2010). By examining whether experimental control of an independent variable produces a consistent effect on a dependent variable, SCDs can determine whether a functional relation exists between the two (Kennedy, 2005). Individual performance of each participant is examined prior to, during, and after the intervention (Horner et al., 2005). Although disagreements exist regarding the minimum number of participants required within a SCD to lend support that an intervention is efficacious, Chambless and Hollon (1998) suggest that three or more are required, along with replication of the study from another independent research site, to suggest that the treatment is "possibly efficacious."

This study used a multiple-baseline-across-participants SCD model. This model requires that participants begin the initial baseline phase at the same time and they are then staggered into the intervention phase, such that each participant not only serves as his or her own control but is also the unit of analysis (Horner et al., 2005). By staggering the introduction of additional participants, researchers are able test whether the effect of the intervention on a single case replicates multiple times and therefore permits within- and between-participant comparisons (Kratochwill et al., 2010). Doing so helps control for threats to internal validity (Horner et al., 2005). Kratochwill et al. (2010) state that staggering participants also permits causal inferences to be made on the effect of the intervention on the outcomes.

Neurofeedback training based on qEEG-guided protocols is the independent variable. Reading achievement (as measured by scores on the GORT-5, AIMSweb Maze, and DIBELS ORF) and attention (as measured by the IVA+Plus and SAT) serve as the dependent variables. Pre- and post-intervention qEEG maps were compared to examine changes in brain function. Participants selected during the screening process were randomly assigned to one of three sets (Cohort 1, 2, and 3), with two participants in the first two cohorts and one in the last.

Baseline phase. All five participants began the baseline phase at the same time. During this phase, EEG assessment commenced and students were introduced to the neurofeedback equipment and software. After ensuring good connections, EEG was monitored for 3 min using an eyes-open condition. Although monitoring continued throughout baseline, participants did not receive neurofeedback training.

Progress monitoring also commenced during this phase and each participant was assessed on a daily basis with the Maze, ORF, and SAT. Once Cohort 1 had established a stable EEG theta/beta ratio, they proceeded to the intervention phase where they received 30 min of neurofeedback training, five days per week, for 40 sessions. In the event of absences or other unforeseen circumstances, training continued until 40 sessions were completed.

Intervention phase. During the first week of the intervention phase, participants received an additional 4 min of training each day to reduce electromyographic (EMG) artifact caused by facial muscle movement. As mean amplitudes of EEG bandwidths fluctuate throughout the day, as well as from day-to-day, the neurofeedback system used provides an automated assessment of EEG to calibrate neurofeedback training goals to adjust for these differences. During this study, a 3-min assessment was conducted at the beginning of each session; the software evaluated the current mean amplitudes of bandwidths being trained and adjusted daily goals accordingly.

During neurofeedback training, participants received rewards that were both visual and aural: Visual rewards were provided in the form of an animated figure moving across on the computer monitor driven by the amplitude of the participant's EEG, and aural rewards were provided by the presence of music or other sounds to indicate success. Failure to meet goals resulted in no (or reduced) movement and sound. Meeting goals for both bandwidths (e.g., theta and beta) simultaneously resulted in faster movement of the animation and increased the volume of sound/music. Each neurofeedback game used the neurofeedback system's default setting to allow participants to successfully meet goals for each bandwidth 84 percent of the time, and both bandwidths simultaneously 71 percent of the time. These goals were set each day, prior to the training, based on the 3-min assessment of each participant's EEG.

When visual assessment of the EEG of one or more participants in Cohort 1 indicated change in the desired direction (e.g., an increase in amplitude of SMR/beta and decrease in theta), Cohort 2 began receiving the intervention. This process was repeated until all cohorts had been staggered in.

Neurofeedback protocols. This study was designed to use theta/beta ratio training protocols, with all participants being trained to inhibit theta and enhance SMR/beta, as first described by Lubar (1991). We used the theta/beta protocol in which theta (4 to 8 Hz) is suppressed and beta (16 to 20 Hz) is enhanced (Monastra et al., 2005). The first 10 sessions used standardized theta/beta protocols for all participants, after which qEEG-guided protocols were used for the final 30 sessions of the intervention, which addressed the unique EEG profiles of each participant to maximize the efficacy of the neurofeedback training (Table 2). The qEEG-guided protocols were designed to normalize qEEG.

Table 2

Neurofeedback Training Protocols Used During the Study

Participant	Phase	# of Sessions	Training	Active	Reference	Enhance (Hz)	Inhibit (Hz)	
Mildred	1	10	Beta	Cz	A1	15 to 18	4 to 8	18 to 30
	2	20	SMR	C4	T5	12 to 15	4 to 10	18 to 30
	3	10	Dual Inhibit	Fz	Pz	N/A	4 to 10	18 to 30
Dudley	1	10	Beta	Cz	A1	15 to 18	4 to 8	18 to 30
	2	20	SMR	T6	Cz	12 to 15	4 to 12	18 to 30
	3	10	Dual Inhibit	Fz	A1	N/A	4 to 12	18 to 30
Nimrod	1	10	Beta	Cz	A1	15 to 18	4 to 8	18 to 30
	2	20	SMR	C4	T5	12 to 15	4 to 12	18 to 30
	3	10	Beta	Fz	A1	15 to 18	4 to 12	18 to 30
Webster	1	10	Beta	Cz	A1	15 to 18	4 to 8	18 to 30
	2	20	SMR	T6	Cz	12 to 15	4 to 12	18 to 30
	3	10	Beta	Fz	A1	15 to 18	4 to 12	18 to 30
Egbert	1	10	Beta	Cz	A1	15 to 18	4 to 8	18 to 30
	2	20	SMR	Cz	A1	12 to 15	4 to 12	18 to 30
	3	10	Dual Inhibit	Fz	A1	N/A	4 to 12	18 to 30

Note. For Phase 1, all participants received the same protocol; Phases 2 and 3 used customized qEEG-guided protocols. SMR = Sensorimotor Rhythm; Dual Inhibit = training protocol where two bandwidths are inhibited and no bandwidth is enhanced.

During the establishment of baseline, EEG recordings were made with a monopolar montage using an active electrode placed at Cz (top center on the scalp) as this location is considered optimal for training (Lubar, 1991). Reference and ground electrodes were placed at A1 and A2, respectively. Mean amplitudes of each participant's theta (4 to 8 Hz) were recorded using an eyes-open condition for 3 min per session. Two subsets of the beta bandwidth (15 to 18 Hz and 16 to 20 Hz) were also monitored as both of these have been reported in the literature (Gruzelier & Egner, 2005; Monastra et al., 2005). Following the completion of three baseline sessions with all participants, theta/beta ratios were calculated using each of the two beta bandwidths recorded and compared. It was found that for all participants, theta/beta ratios were higher when calculated with the beta bandwidth at 15 to 18 Hz. Given that reductions in the theta/beta ratio are associated with increased attentiveness, the decision was made to provide all participants with 10 sessions of neurofeedback in which theta (4 to 8 Hz) was inhibited and beta (15 to 18) was enhanced.

Students in all cohorts received the same protocol for the first phase, while the second and third phases were customized based on individual qEEG profiles. Neurofeedback sessions were provided each school day at approximately the same time until every participant had received 40 sessions. Absences, field trips, and special events were accounted for, and students who missed sessions continued with the intervention until they had completed 40 sessions.

Incentives. Neurofeedback can be engaging, especially for motivated adults and adolescents who find that training is intrinsically rewarding and perceive it as a positive way to reduce symptoms and achieve control over unwanted behaviors (Rossiter, 2002). Others, particularly children who do not yet understand the implications of the disorder or the potential for long-term benefits associated with neurofeedback to alleviate symptoms associated with ADHD, can find that their interest in training wanes after the novelty of the invention dissipates and becomes routine. Thus, a reward system was established that was non-contingent on performance but as an incentive to complete each daily session. Initially, students were provided with a chart and for each day that they responded in the affirmative to the question, "Did you try your best today?" were permitted to select a shiny metallic star sticker to record their

participation. At the end of each week, students who received stars each day earned a "Friday Surprise"—a small reward valued at ≤ $1.

Follow-up

Given the important role that reading achievement plays in academic success, as well as the amount of time required for students to receive 40 sessions of neurofeedback during the school day, there is a need to examine the robustness of the intervention over time. In order to do so, each participant was reevaluated after summer vacation and near the beginning of the following school year. Specifically, the Conners 3AI, the GORT-5, and the IVA+Plus were administered. All follow-up results were calculated based on norms that reflected the age of each of the participants, as well as their advancement to fifth grade. As noted previously, Form 1 of the GORT-5 was used.

Data Analysis

SCD traditionally relies on systematic visual analysis of data, in which relations between the independent and dependent variables are sought, as well as the strength of the relation between them (Horner et al., 2005; Kennedy, 2005; Kratochwill et al., 2010). As data are gathered, they are plotted and visually inspected to determine if a causal relation can be inferred by changes in the outcome that is attributable to manipulations of an intervention. Effects can be demonstrated when there are observable changes between consecutive phases (i.e., baseline and intervention) that differ from what is expected due to manipulation of the independent variable.

Results

Between the onset of the baseline phase and completion of the intervention phase, participants received 43 to 49 daily sessions; variation in the number of sessions was due to differential baseline phase lengths. The intervention was divided into three phases with all students receiving the same theta beta reduction protocol during Phase 1: inhibit theta (4 to 8 Hz) and enhance beta (15 to 18 Hz) for the first 10 sessions. Phases 2 and 3 used qEEG-guided protocols and contained 20 sessions and 10 sessions, respectively. Progress was monitored using Maze, ORF, and SAT. Post-intervention and follow-up outcomes were measured using the Conners 3AI, the IVA+Plus, and the GORT-5.

Attention Measures

CNS-VS SAT results. Visual examination of the results for the CNS-VS SAT across all phases revealed that three participants increased in correct responses with neurofeedback and two participants (Mildred and Nimrod) neither increased nor decreased their performance (Figure 1). All participants reduced their errors over the same period. Performance pertaining to reaction time was mixed; three participants, Dudley, Webster, and Egbert demonstrated improved (faster) performance, while Mildred and Nimrod performed slower over time. All students increased their accuracy; the mean percentage of correct responses at pretest was 70.22%; that increased to 87.06% during Phase 3.

Conners 3AI results. Both parent and teacher ratings on the Conners 3AI showed improvements for most participants on all measures (Table 3). The one exception was Nimrod, whose parent gave him a raw score of zero at pretest and posttest. Nimrod's teacher, however, indicated a large improvement with his raw score dropping from 18 on the pretest, to 0 on the posttest. The mean raw score for all participants on the parent scale at pretest was 11.20 (*SD* = 6.72), which dropped to 6.20 (*SD* = 4.55) at posttest. Similar declines in scores were noted on the teacher ratings; the mean raw pretest score was 15.60 (*SD* = 2.88) which dropped to 8.4 (*SD* = 5.86) at posttest.

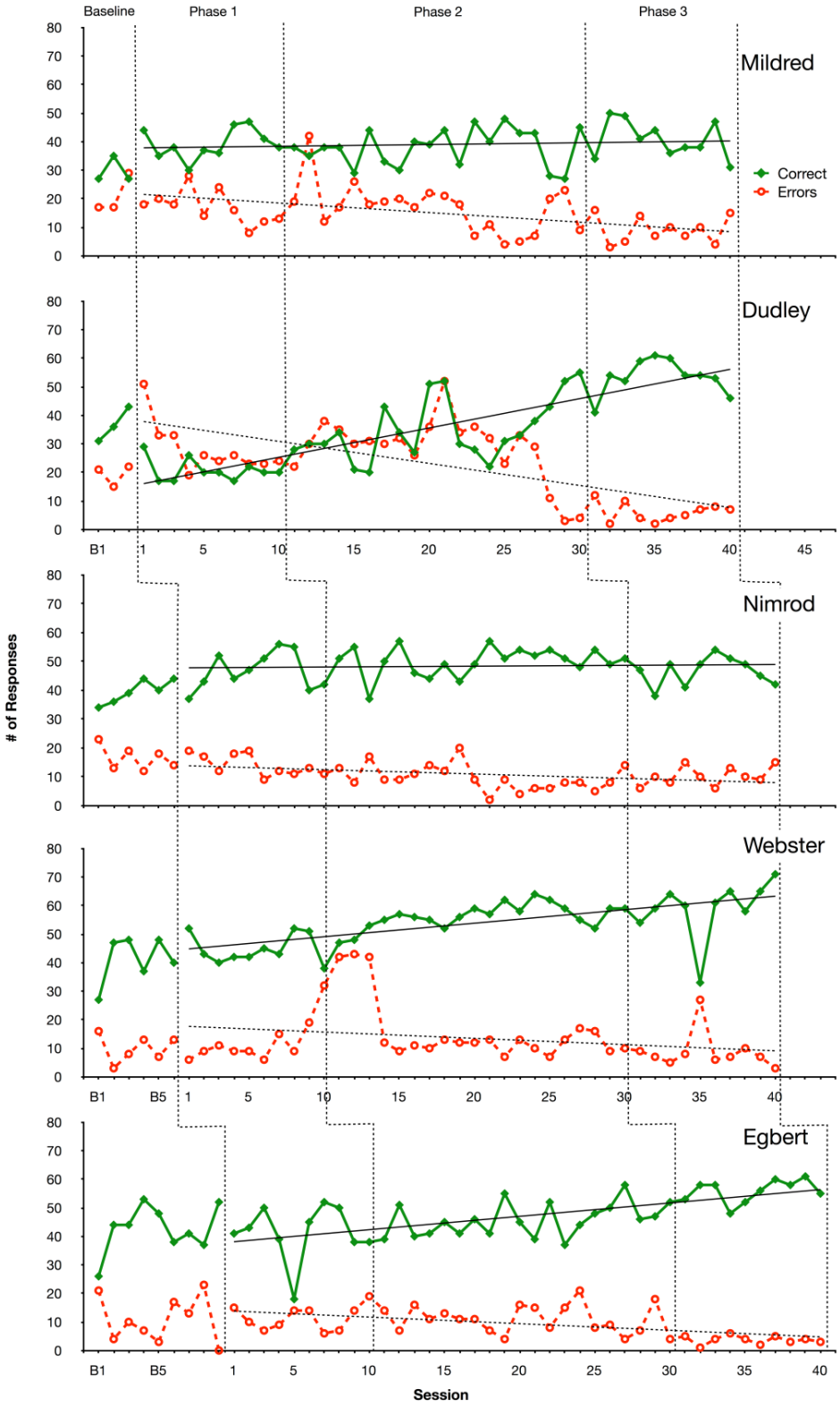

Figure 1. CNS-VS SAT correct responses and errors, trends across all phases. Trends that were expected to increase are represented by a solid line; trends that were expected to decrease are represented by a dotted line. The baseline phase commenced on the same day with participants receiving no more than one session per day.

Table 3

Conners 3AI Pretest, Posttest, and Follow-up Scores

		Participant					All Participants	
		Mildred	Dudley	Nimrod	Webster	Egbert	Mean	*SD*
Conners 3AI-Parent								
Raw Score	Pretest	16	10	0	16	14	11.20	6.72
	Posttest	**8**	**9**	0	**3**	**11**	**6.20**	4.55
	Follow-up[b]	19	10	0	**1**	**8**	6.20	8.23
Probability (%)	Pretest	99	91	11	99	99		
	Posttest	**82**	**87**	11	**51**	**94**		
	Follow-up[b]	99	91	11	**29**	**82**		
T-score	Pretest	≥ 90	≥ 90	45	≥ 90	≥ 90		
(Cutoff ≥ 61)[a]	Posttest	≥ 90	≥ 90	45	**61**	≥ 90		
	Follow-up[b]	≥ 90	≥ 90	45	**49**	**86**		
Conners 3AI-Teacher								
Raw Score	Pretest	18	12	18	13	17	15.60	2.88
	Posttest	**13**	**10**	**0**	**5**	**14**	**8.40**	5.86
	Follow-up[b,c]	**7**	**4**	0	**0**	**3**	**2.80**	2.95
Probability (%)	Pretest	97	89	97	91	96		
	Posttest	**91**	**84**	**19**	**64**	**92**		
	Follow-up[b,c]	**73**	**58**	19	**19**	**52**		
T-score	Pretest	≥ 90	≥ 90	≥ 90	≥ 90	≥ 90		
(Cutoff ≥ 61)[a]	Posttest	≥ 90	**86**	**45**	**65**	≥ 90		
	Follow-up[b,c]	≥ 90	**62**	**44**	**44**	**57**		

Note. Posttest and follow-up results in bold indicate change in the desired direction over previous score. Probability (%) = percentage of time that children in the norming sample with the same score had a diagnosis of ADHD as opposed to typically developing children (Conners & Research and Development Department, 2009).
[a]The maximum T-Score reported by the test developers is ≥ 90. [b]Follow-up was conducted approximately five and a half months after posttest. [c]Conners 3AI-Teacher follow-up ratings were completed by fifth-grade teachers (pretest and posttest ratings were completed by fourth-grade teachers).

IVA+Plus results. At posttest, all participants demonstrated improvements in their Combined Sustained Attention scores, except for Dudley (Table 4). While this participant appeared engaged during the test, he was observed responding very quickly to the target. His scores were inconsistent from those obtained at pretest. An examination of these posttest results revealed tremendous variability with standard scores ranging from 0 to 157. These scores suggest that this participant was not motivated to do his best and therefore his IVA+Plus scores for the posttest administration must be viewed with caution. Even when Dudley's scores are considered, group results are positive. For all participants, the group mean scores on the C-SA scale at pretest was 58.60 (*SD* = 27.47), which increased to 68.40 (*SD* = 35.59) at posttest; the A-SA scale at pretest was 61.00 (*SD* = 35.85) and increased to 67.80 (*SD* = 35.95) at posttest; and the V-SA scale was 64.00 (*SD* = 29.81) at pretest and increased to 74.80 (*SD* = 29.06) at posttest. At posttest, the algorithms used by the IVA+Plus Interpretive Flowchart no longer suggested a diagnosis for ADHD for two students, Nimrod and Webster, while a diagnosis continued to be suggested for Mildred, Egbert, and Dudley.

Table 4

IVA+Plus Pretest and Posttest Sustained Attention Standard Scores

		Participant					All Participants	
		Mildred	Dudley[a]	Nimrod	Webster	Egbert	Mean	*SD*
Subtest								
C-SA	Pretest	42	28	91	84	48	58.60	27.47
	Posttest	**70**	7	**96**	**87**	**82**	**68.40**	35.59
	Follow-up[b]	**73**	**47**	**94**	**107**	66	**77.40**	23.49
A-SA	Pretest	10	52	83	105	55	61.00	35.84
	Posttest	**55**	10	**92**	**92**	**90**	**67.80**	35.95
	Follow-up[b]	**83**	**45**	88	**110**	69	**79.00**	24.05
V-SA	Pretest	80	21	100	67	52	64.00	29.81
	Posttest	**88**	**25**	100	**84**	**77**	**74.80**	29.06
	Follow-up[b]	73	**61**	**101**	**103**	71	**81.80**	19.01
Supports Diagnosis[c]								
	Pretest	Yes	Yes	Yes	Yes	Yes		
	Posttest	Yes	Yes	**No**	**No**	Yes		
	Follow-up[b]	Yes	Yes	**No**	**No**	Yes		

Note. Posttest results in bold indicate change in the desired direction. C-SA = Combined Sustained Attention; A-SA = Auditory Sustained Attention; V-SA = Visual Sustained Attention.
[a]Analysis of Dudley's posttest results must be interpreted with caution. [b]Follow-up was conducted approximately five and a half months after posttest. [c]As determined by algorithms used by the IVA+Plus Interpretive Flowchart.

Reading Measures

DIBELS ORF results. Although on average reading rate improved from 85.04 words correct at baseline to 88.64 at Phase 3, this improvement is minimal and less than expected of typical fourth graders (Figure 2). However, trend lines for accuracy indicate that all participants except Mildred exhibited some improvement in the percentage of words read correctly per minute, which means that most participants made fewer errors as the study progressed.

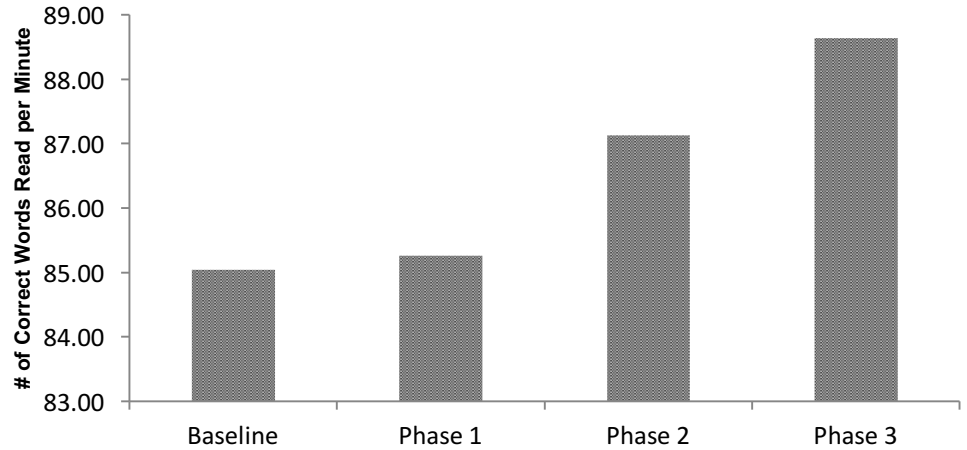

Figure 2. DIBELS ORF mean of correct words for all participants across phases. Fourth-grade students are considered "at risk" if mean words per minute ≤ 95 at the end of the school year (University of Oregon Center on Teaching and Learning, 2012).

AIMSweb Maze results. All participants exhibited changes in the desired direction on both AIMSweb Maze scores; the number of words correct increased and the number of errors decreased (Figure 3). When participants' scores are combined, the mean number of correct word choices increased from 15.04 at baseline to 18.18 at Phase 3.

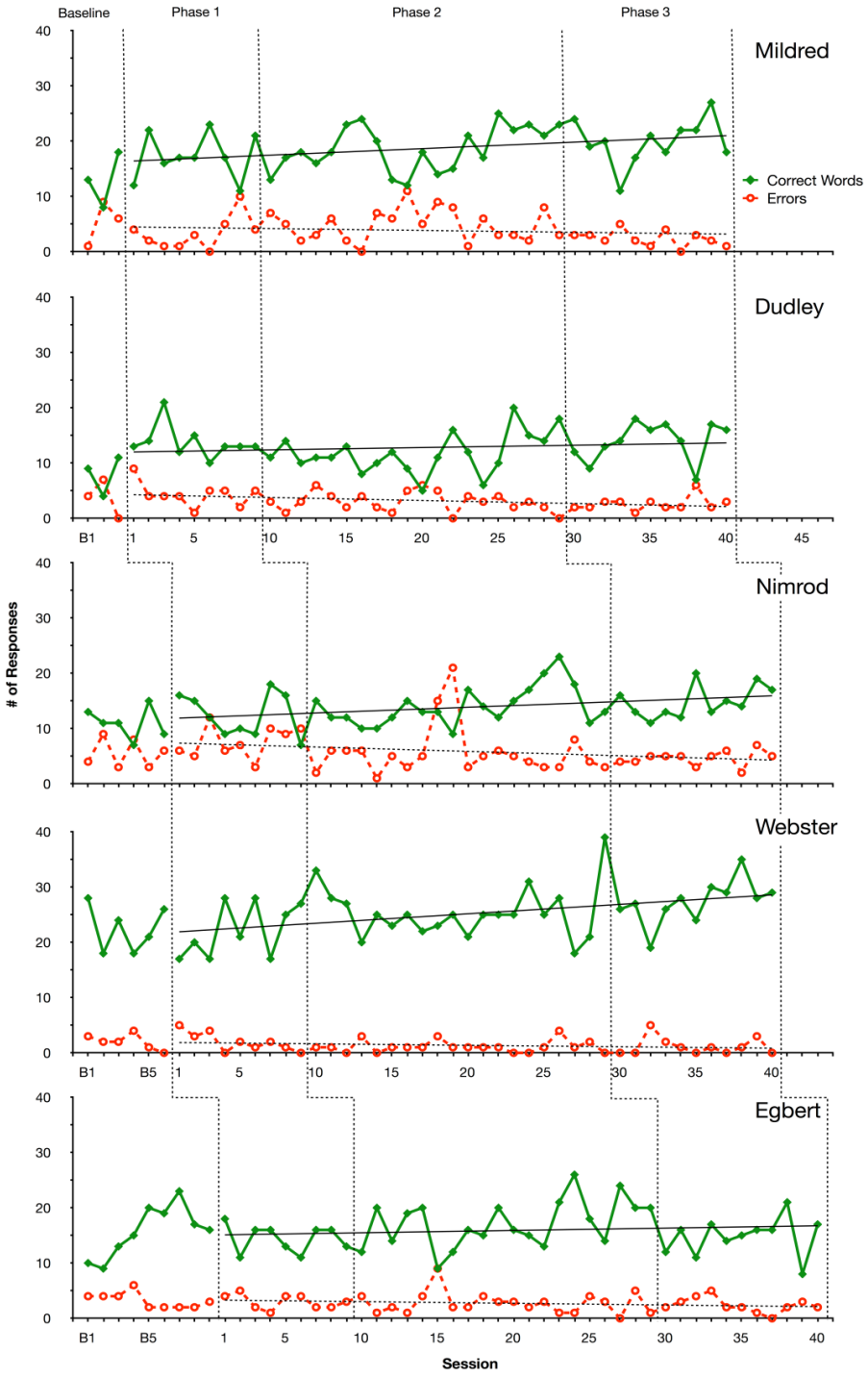

Figure 3. Maze words correct and errors, trends across all phases. Trends that were expected to increase are represented by a solid line; trends that were expected to decrease are represented by a dotted line.

GORT-5 results. All participants except Egbert increased their ORI standard scores between pretest and posttests (Table 5). The mean standard score increased from 83 (*SD* = 9.14) to 90.60 (*SD* = 8.32). Egbert's ORI had a slight drop from 86 to 84; as the standard error of measurement (SEM) on the ORI is 3 (Wiederholt & Bryant, 2012b), this decline does not appear to be meaningful. Similar results were obtained on the fluency score, which is derived from two additional scaled scores, rate and accuracy. Four participants increased their scaled scores, while Egbert had a decrease (from 9 to 6). The mean fluency scaled score increased from 7.00 (*SD* = 2.12) to 7.60 (*SD* = 1.52). The mean rate score showed a slight decline, from 7.80 at pretest to 7.60 at posttest. The SEM for both the rate and fluency scores is 1. As no participants increased or decreased ± 1 point in their rate score at posttest, no meaningful changes occurred in rate following the intervention. The group accuracy score, however, increased from 7.00 to 8.60, with participants gaining 1 point (Mildred), 2 points (Webster), 3 points (Nimrod), and 4 points (Dudley), except Egbert whose accuracy dropped 2 points. All participants increased their comprehension scaled scores by at least 2 points (i.e. on average from 6.80 to 9.00).

Table 5

GORT-5 Pretest and Posttest Results

		Participant					All Participants	
		Mildred	Dudley[a]	Nimrod	Webster	Egbert	Mean	*SD*
Oral Reading Index[a]								
	Pretest	81	73	78	97	86	83.00	9.14
	Posttest	**89**	**86**	**89**	**105**	84	**90.60**	8.32
	Follow-up[c]	**97**	**89**	**92**	105	**92**	**95.00**	6.28
Rate[b]								
	Pretest	7	5	8	10	9	7.80	1.92
	Posttest	**8**	**6**	7	9	8	7.60	1.14
	Follow-up[c]	**9**	**7**	**9**	**10**	7	**8.40**	1.34
Accuracy[b]								
	Pretest	6	4	6	9	10	7.00	2.45
	Posttest	**7**	**8**	**9**	**11**	8	**8.60**	1.52
	Follow-up[c]	7	7	8	10	**9**	**8.20**	1.30
Fluency[b]								
	Pretest	6	4	7	9	9	7.00	2.12
	Posttest	**7**	**7**	**8**	**10**	6	**7.60**	1.52
	Follow-up[c]	**8**	7	8	10	**8**	**8.20**	1.10
Comprehension[b]								
	Pretest	7	6	5	10	6	6.80	1.92
	Posttest	**9**	**8**	**8**	**12**	**8**	**9.00**	1.73
	Follow-up[c]	**11**	**9**	**9**	12	**9**	**10.00**	1.41

Note. Posttest and follow-up results in bold indicate change over previous score in the desired direction.
[a]Standard Scores. [b]Scaled Scores (range = 1 to 20, mean = 10). [c]Follow-up was conducted approximately five and a half months after posttest.

EEG/qEEG Measures

Theta/beta results. The neurofeedback protocols used in this research were qEEG-guided and, therefore, individualized for each participant. The qEEG results for each participant reported that there were general improvements observed in each participant's EEG, with the exception of Egbert's. Pretest and posttest qEEG theta/beta power ratios exhibited changes in the desired direction for all participants except for Dudley (Table 6). Power ratios are calculated by dividing the amplitude (μV) of theta squared by the amplitude of beta squared: $theta^2/beta^2$.

Table 6

qEEG Pretest and Posttest FFT Theta/Beta Power Ratios

	Eyes Closed	
	Pretest	Posttest
Mildred	5.97	**5.77**
Dudley	3.88	4.29
Nimrod	1.97	**1.52**
Webster	4.40	**3.65**
Egbert	2.00	**1.92**

Note. Posttest results in bold indicate change in the desired direction. FFT = Fast Fourier Transform. The qEEG report provided information on theta/beta power ratios calculated as $(theta)^2$ / $(beta)^2$. Theta was defined as (4 to 8 Hz) and beta as (13 to 21 Hz).

Follow-up Assessments

Follow-up assessments (Conners 3AI, GORT-5, and the IVA+Plus) were conducted near the beginning of the following school year (November 2013), approximately five and a half months following the completion of posttest assessments. The Conners 3AI was again completed by parents and teachers, although teacher ratings were completed by each participant's fifth-grade teacher. Overall, teachers' ratings on the Conners 3AI-T showed improvement for four participants, with one participant (Nimrod) maintaining the score observed at posttest.

All five participants received higher scores at follow-up, compared to pretest results on the C-SA (Combined Sustained Attention) score (Table 4), the primary index of attention on the IVA+Plus. Two students, Nimrod and Egbert, received lower scores than obtained at posttest, although their scores remained above pretest. Similar gains were made on the subtests: all five participants received higher scores at follow-up than obtained at pretest on A-SA (Auditory Sustained Attention) with the same two students, Nimrod and Egbert, receiving lower scores than at posttest. Four of five participants made gains on V-SA (Visual Sustained Attention) with one student, Mildred, receiving a lower score than obtained at pretest. Group means for C-SA, as well as A-SA and V-SA increased from pretest to posttest, as well as from posttest to follow-up.

Positive performance was also observed on the GORT-5 at follow-up (Table 5). Four of the five participants obtained higher scores on ORI and one student maintained the score obtained at posttest. Accuracy scores remained the same for one participant, three participants declined one scaled score although these scores remained higher than observed at pretest, and one participant (Egbert) had an increase of one scaled score although his score remained lower than at pretest. Similar to the ORI, four of the five participants' reading comprehension scores improved while one student (Webster) maintained the score he received at posttest. Because follow-up data were collected in Grade 5, GORT-5 scores are based upon the normative data for fifth-grade students, rather than fourth grade.

Discussion

A growing body of scientific literature suggests that the efficacy of neurofeedback as an intervention to assist individuals with attention deficits holds promise. Although improvements in academic performance have been observed for many decades, beginning with the seminal case study by Lubar and Shouse (1976) that noted increases in sustained attention and improvements in school performance, research has been conducted almost exclusively in clinical settings. To date, just a handful of studies have been conducted in K–12 school settings, and all those, with the exception of Orlando and Rivera (2004), have focused exclusively on the improvement of attention with effects on academic achievement being noted only anecdotally. Thus, this study is one of the first to explicitly examine not only attention but also reading fluency and comprehension in a public school. Following 40 sessions of neurofeedback, participants demonstrated improvements on measures of attention, reading accuracy (but not fluency), and improvements on measures of reading comprehension that exceeded growth that might otherwise be attributable to maturation or regular classroom instruction.

Improvements on Objective Measures of Attention

As predicted, our hypothesis that measurable improvements would occur in attention on objective measures (i.e., CPTs) was confirmed. In our study, the IVA+Plus was used at pretest and posttest, as well as at follow-up, as a longer measure of auditory and visual attention, and all students except Dudley (as discussed previously) showed improvement at posttest (Table 4). Furthermore, all participants, including Dudley, had higher scores at follow-up than at pretest. These findings indicate that 40 sessions of neurofeedback improved attention as predicted.

The SAT was used following each session of neurofeedback as an objective measure to monitor changes in attention. The SAT is a hybrid of traditional CPTs (i.e., the IVA+Plus), that focus on constructs such as errors of commission and omission, as well as reaction time, and a Stroop color test, which serves as a measure of executive function. Specifically, the SAT requires participants to read a word and make a decision in response to what they have read. Thus, the assessment monitors, on a very basic level, a task associated with reading comprehension by requiring participants to correctly identify responses to written prompts. As participants made consistent gains on correctly identifying targets, with all demonstrating an increase in the number of correct responses over the course of the intervention, our results suggest that neurofeedback not only improved attention but also executive function.

Effect of Neurofeedback on Reading Fluency

The literature is essentially silent on efficacious interventions to improve fluency with ADHD populations. Theorists have long postulated that attention plays an integral role in the reading process and that it is a critical component that permits readers to derive meaning from text. The role of attention may be particularly important in assisting those whose reading abilities lack automaticity, as they must attend to the processes of reading words, rather than focus on comprehension (LaBerge & Samuels, 1974). Furthermore, reading fluency, which combines reading rate and accuracy, is strongly correlated with reading comprehension (O'Connor et al., 2002). For these reasons, it seemed plausible to us that improved attention could influence reading rate.

That was not the case. Although neurofeedback improved attention, few changes were observed in reading fluency whether measured during progress monitoring (DIBELS ORF) or on the reading rate outcome (GORT-5, Reading Rate). Instead, all participants except Mildred exhibited improvement in the percentage of words read correctly per minute. Thus, most participants improved their accuracy and made fewer errors as the study progressed, and it appears neurofeedback helped participants to read with more focused attention to content.

Influence of Neurofeedback on Reading Comprehension

The most encouraging outcome of this study pertains to the effect of neurofeedback on reading comprehension. While previous neurofeedback studies have reported improvements in reading comprehension incidentally to their declared dependent variables, none have explicitly examined the issue. On the progress monitoring measure (Maze) that focused on comprehension primarily at the sentence level, an examination of the means of correct word choices for all participants across phases reveals an increase in the number of correct responses, which is consistent with our finding that participants also read with increased accuracy. Specifically, the Maze results suggest that the intervention was responsible for growth beyond what would be expected. When the means of correct word choices for all participants across phases is examined, an increase is observed in the number of correct word choices identified over time (Figure 4). However, when the increases for all participants (as a group) are compared to the AIMSweb National Norms Table (NCS Pearson, 2013), which was developed with a large sample of fourth graders (n = 24,881) and provides norms calculated at three intervals across the school year (fall, winter, and spring), participants' gains are larger than expected. Specially, the normative sample indicates that no changes are observed typically between winter and spring (e.g., the mean raw score for winter and spring are 21 correct word choices). The mean of participants' scores, between baseline (m = 15.04 correct word choices) and Phase 3 (m = 18.18 correct word choices) increased by 3.14 correct word choices. Given that the study commenced in March 2013 and concluded 12 weeks later in June 2013, suggests that neurofeedback training may have improved comprehension as measured on the Maze.

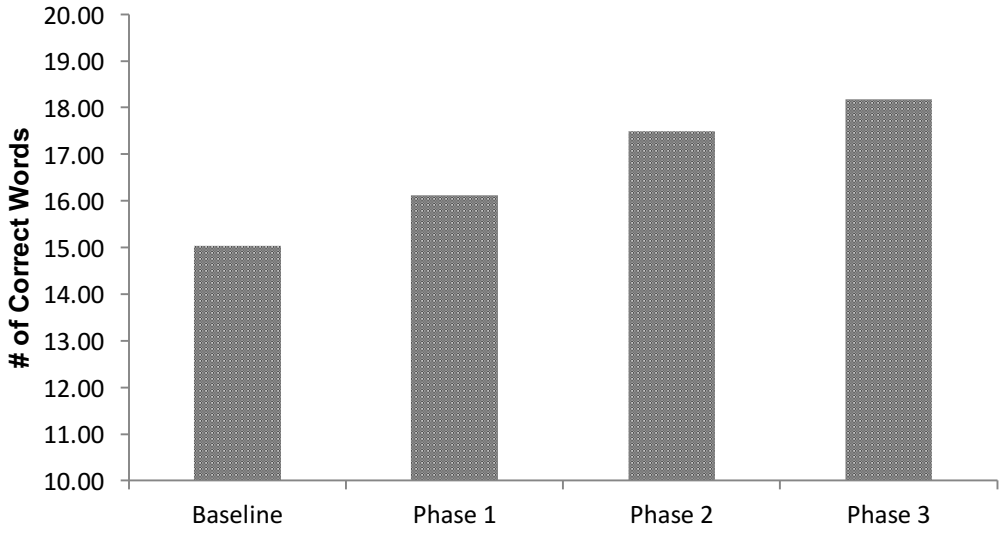

Figure 4. Maze mean of correct word choices for all participants across phases.

Perhaps more importantly, pretest and posttest of reading comprehension was measured using the GORT-5 and provided additional evidence that reading comprehension improved. After each story is read, participants answer passage-dependent questions that not only rely on the content of the text but also require them to recall what has just been read. Thus, reading as assessed on the GORT-5 provides a view commensurate with reading requirements in schools. When viewed in this context, the gains made by all students, with the exception of Egbert, indicate that reading comprehension improved following 40 sessions of neurofeedback. An evaluation of each participant's EEG also supports this conclusion; each of the five participants in this study exhibited improvements through either reduction of theta/beta ratios or normalization of EEG through improved coherence.

One issue arises in relation to measurement of changes in reading comprehension scores: The Maze assessment requires that participants read silently, while the GORT-5 requires them to read aloud. This difference presents a problem when attempting to compare the results of each assessment, because it is difficult to monitor student engagement when reading silently. Schuck (2008) observed that students with ADHD appear to read more slowly when reading silently than when reading orally and that prompting was required to keep them engaged. She concluded that participants performed significantly better on measures of comprehension while reading orally, rather than silently. In our study, during the Maze task students were observed diverting their attention elsewhere; they would look about the room or play with the pencil used for their responses. When these behaviors were evident, students were guided back to the reading task. Unfortunately, we did not include a silent reading comprehension task that had similar demands to the GORT-5; however, comparing oral and silent reading comprehension of students with ADHD could be a fruitful area for further research. The overall findings of this study suggest that neurofeedback training improves reading comprehension when given tasks that most resemble those that reflect reading for content.

Limitations

Single-case research is intended to observe the effects of an intervention to alter behavior; it seeks to establish a causal relationship between an independent variable and the dependent variables. Thus, small sample sizes are permissible and the emphasis is on the observation of effects. In keeping with SCD guidelines, this study used a sample of five students. Although effects were clearly observed, caution is advised as these results cannot be generalized to larger populations. Further research is warranted, especially since no other studies have yet directly examined the effects of neurofeedback on reading comprehension.

School schedules. Under the best of circumstances, schools are busy places and days are filled with activities. Schedules are subject to changes, some planned and others not. It is against

this backdrop that the intensive intervention schedule of this study was overlaid. Significant events included Spring Break, as well as a week of standardized testing. Special activities included concerts, field trips, movies, plays, picnics, and other events. Although we adapted to changes in the schedule, there were times when participants' neurofeedback sessions had to be rearranged. When possible, students were scheduled as close to their normal times as possible.

Social Validity

The intensity of conducting 40 sessions of neurofeedback, particularly when training was scheduled on a daily basis, was an issue that was researched and embedded into the design of this study. The star charts and use of incentives, as described earlier, appeared to work well. As a group, participants regularly expressed satisfaction with the training sessions with several commenting that participation in the study was "awesome." Three students—Mildred, Nimrod, and Egbert—asked if they were going to continue neurofeedback during the next school year. All expressed disappointment when told that the study would not continue after summer vacation.

Although the overall enthusiasm of the participants was beneficial, it was evident that at least two participants (Mildred and Egbert) also enjoyed coming to sessions because they missed class. As both of these students were generally affable and congenial, it appeared as if they especially enjoyed the individual attention received throughout the study. With both of these students, however, encouragement was regularly provided to keep them focused on doing their best during training.

Implications and Future Research

To date, only a handful of studies have examined the use of neurofeedback in public schools. This study is the one of the earliest to explicitly explore the utility of neurofeedback as an intervention to improve reading achievement in a public school setting. It is also unique in that it focused on symptoms of inattention and not hyperactivity (the samples of the other studies conducted in public schools all appear to have included children with hyperactivity/impulsivity). Specifically, this study examined the impact conditioning of EEG has on reading fluency and comprehension.

Measures of reading fluency demonstrated mixed or limited results. Other than a slight increase in accuracy, the changes in DIBELS ORF results were negligible. It is not until rate, accuracy, and fluency are examined on the longer passages found on the GORT-5 that a pattern emerges; rate remained relatively static while accuracy increased. This suggests that participants became more attentive to the text and thus read with improved accuracy (therefore, they also made fewer errors) with little or no change in rate.

The results indicate that all participants displayed increases in reading comprehension on the GORT-5. Similar findings were also evident on the Maze, despite the use of considerably shorter passages as well as an assessment that does not rely on memory. Future research could examine differential performance on reading comprehension measures that rely on oral or silent reading, and on memory versus those that permit text to be reviewed, especially since all of these conditions are found in academic settings. For example, memory-dependent reading comprehension skills are necessary when students read for content that must be retained, while text-dependent reading is used for assessments in the classroom and for seeking information.

Results from follow-up assessments indicate four of the five participants exhibited improvements on the primary measure of attention (C-SA) on the IVA+Plus. Furthermore, gains observed on the GORT-5 measure of reading achievement also appear to be robust. Specifically, four of the five participants achieved higher ORI and Reading Comprehension standardized scores at follow-up than observed at posttest; the remaining participant (Webster) maintained the same score on both indices as obtained at posttest. These findings imply that neurofeedback may be a viable option to assist children with attention deficits as an intervention strategy for improving both attention and reading comprehension.

While the experimental design required the use of a small sample and cannot be generalized to a larger population, this study has demonstrated potential for neurofeedback to improve educational opportunities for school children. Findings that attention improved, as measured by CPTs, are consistent with existing literature. Moreover, these improvements in attention maintained well into the next school year. Even more importantly, four of the five participants made positive gains on the GORT-5 Oral Reading Index. The one student who did not show gains on the ORI also displayed the least change in EEG; he may have been a non- or slow-responder to neurofeedback, or perhaps other issues, such as motivation, may have been involved. The overall

findings suggest that the use of neurofeedback in a public school setting is worthy of continued exploration. The body of scientific literature on the efficacy of neurofeedback as an intervention strategy to improve the lives of individuals with attention deficits, as well as many other disorders, continues to grow. Currently, there remains a need for research in K–12 school settings. Recent meta-analyses that indicates it is a promising intervention (Arns, de Ridder, Strehl, Breteler, & Coenen, 2009; Hodgson, Hutchinson, & Denson, 2012) lends support to the need for additional research. This study provides one of the early glimpses on the use of neurofeedback in a public school setting. The findings suggest that neurofeedback may be a viable option to assist children with attention deficits as an intervention strategy for improving both attention and reading achievement.

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NeuroRegulation

Passive Infrared Hemoencephalography (pIR HEG) for the Treatment of Migraine Without Aura

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Abstract

Objective: To evaluate the impact of Passive Infrared Hemoencephalography (pIR HEG) in reducing headache-related disability in adults with migraine without aura (MWOA). **Methods:** This quasi-experimental study enrolled 31 adults (*M* age = 38.65 years, range = 20–65 years) who met the *International Classification of Headache Disorders* (2nd ed.) criteria for migraine without aura (MWOA; IHS, 2004). All participants received the treatment. Participants completed a 10-week protocol of pIR HEG. Changes in headache impact were assessed at three points in time: baseline, after six treatment sessions, and after 10 treatment sessions. **Outcome Measures:** Headache Impact Test (HIT-6) and the Migraine Disability Assessment (MIDAS) questionnaire. **Results:** Significant reductions in HIT-6 scores were found between Pretest and Midtreatment, $p < .001$, and between Pretest and Posttest, $p < .001$. Significant reductions in MIDAS scores were found between Pretest and Posttest, $p < .001$. Results indicated MIDAS subscale A scores did not significantly change across the three time points. Significant reductions in MIDAS subscale B scores were found between Pretest and Midtreatment, $p < .001$, and between Pretest and Posttest, $p < .001$. In this study, pIR HEG appeared to be effective by the end of treatment in reducing the impact of headache-related disability among the participants.

Keywords: migraine without aura; Passive Infrared Hemoencephalography; Headache Impact Test-6; Migraine Disability Assessment questionnaire; migraine-related disability

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Introduction

Migraine is a highly prevalent, episodic, chronic pain condition characterized by disabling attacks and impaired functioning between attacks (Buse, Rupnow, & Lipton, 2009; Dahlöf & Solomon, 2006; Diamond et al., 2006; International Headache Society [IHS], 2004; Lipton, Stewart, Sawyer, & Edmeads, 2001). Migraine is a primary headache disorder (i.e., headache that lacks a clear diagnostic or biochemical marker; IHS, 2004) that produces substantial physical suffering and impairs functioning. In addition, migraine can place an enormous economic burden on individual sufferers, their families, and on society. Acute migraine attacks are generally characterized by headache of a throbbing or pulsating quality, photophobia (increased sensitivity to light), phonophobia (increased sensitivity to sound), and nausea, vomiting, or both (IHS, 2004). Pain-free periods are often marked by hyper-vigilance, affective distress, diminished energy levels, increased anxiety and fear, and reduced willingness or capacity to participate in work, family, and social activities (Buse et al., 2009).

There is currently no cure for migraine. At best, current treatments can reduce the frequency and severity of acute migraine attacks. Oftentimes, outcomes are optimized when pharmacologic treatments are used in conjunction with nonpharmacologic treatments (Blumenfeld & Tischio, 2003; Buse et al., 2009; Harpole et al., 2003; Lemstra, Stewart, & Olszynski, 2002; Mathew & Tfelt-Hansen, 2006). Although a multidisciplinary approach to treatment often produces the best

outcomes, medications are most commonly used in the treatment of migraine. There has been a proliferation of pharmacologic treatments within the past two decades. Although medications can reduce migraine symptoms, they provide only a partial benefit. Current medications provide some benefit for 50 to 60% of people with migraine (Berg & Ramadan, 2006, p. 35). In addition, pharmacologic therapies are not an option for people with heart disease or who have had a stroke (Tfelt-Hansen, 2006). Due to these and other limitations associated with pharmacologic treatments, many do not receive effective relief.

Nonpharmacologic interventions provide an alternative treatment approach for the treatment and management of the symptoms and the overall impact of migraine. Nonpharmacologic interventions have demonstrated efficacy in reducing the severity and the frequency of migraine (Penzien et al., 2005).

Outcomes for complex disorders like migraine are often optimized when treatment incorporates pharmacologic and nonpharmacologic therapies (Penzien et al., 2005). Pharmacologic treatments are designed to reduce or manage the acute symptoms associated with a migraine attack. Nonpharmacologic treatments are generally designed to address the underlying pathophysiology of migraine. Continued development and evaluation of novel therapies is essential to identify opportunities to reduce the burden of the disease and improve the quality and effectiveness of treatment strategies for migraine.

One relatively new intervention that warrants further examination is Passive Infrared Hemoencephalogy (pIR HEG); which is a nonpharmacologic intervention, developed specifically for the treatment of migraine disorders, that has shown promise in reducing migraine impact (Carmen, 2004). While pIR HEG has been used clinically for over a decade, only one case series (Carmen, 2004) has evaluated the impact of pIR HEG for individuals with migraine disorders. Based on the results of this study, Carmen suggested that pIR HEG may be a useful intervention for reducing the severity of acute attacks of migraine. Although preliminary results appear promising, further studies are needed to determine the effects of pIR HEG in the treatment of migraine. This study is designed to expand on the case series by Carmen (2004) and to contribute to the literature regarding nonpharmacologic interventions for the treatment of migraine.

The primary objective of this study was to evaluate the efficacy of pIR HEG in reducing headache-related disability, attack frequency, and attack severity in a sample of adults with a migraine subtype, migraine without aura (MWOA), based on ICHD diagnostic criteria (see Table 1). Specifically, this study assessed headache-related disability, attack frequency, and attack severity using pretest and posttest measures. Two instruments designed to quantify the impact of headache-related disability, the Headache Impact Test (HIT-6; Nachit-Ouinekh et al., 2005) and the Migraine Disability Assessment (MIDAS; Stewart, Lipton, Whyte, et al., 1999) questionnaire, were used to assess the effectiveness of the intervention. The HIT-6 assesses the global impact of headache-related disability (Dahlöf & Solomon, 2006; Kosinski et al., 2003; Nachit-Ouinekh et al., 2005). The MIDAS questionnaire assesses the functional impact of headache-related disability and includes two subscales that assess the frequency and severity of migraine, respectively (Stewart, Lipton, & Kolodner, 2003; Stewart, Lipton, Kolodner, Liberman, & Sawyer, 1999). When used together, these instruments provide a comprehensive picture of headache impact.

Migraine Headache

Migraine is a chronic and potentially progressive pain disorder that inflicts a very high burden on individual sufferers, their families, and on society (IHS, 2004). Migraine-related disability produces substantial impairment during and between attacks. Attack-related disability ranges from temporary mild impairment to complete incapacitation for days and sometimes weeks. Impairment during pain-free periods produces emotional distress and reduced functioning and productivity.

The degree of disability that migraine causes depends largely on the frequency, duration, and severity of acute attacks. The rate of attack occurrence can range from one to two attacks annually to attacks daily (IHS, 2004). Migraine prevalence typically peaks between 25 and 55 years of age, the most productive years of the life span (Abramson, Hopp, & Epstein, 1980; Bille, 1981; Dalsgaard-Nielsen, Engberg-Pedersen, & Holm, 1970; Lipton et al., 2007, 2002; Lipton, Stewart, Diamond, S., Diamond, M. L., & Reed, 2001; Nikiforow, 1981; Patel et al., 2004; Sillanpää & Anttila, 1996; Stang & Osterhaus, 1993; Steiner, Scher, Stewart, Kolodner, Liberman, & Lipton, 2003; Stewart, Shechter, & Rasmussen, 1994; Stewart, Lipton, Celentano, & Reed, 1992; Stovner & Scher, 2006). Over time, migraine-related disability may

affect the physical and emotional well-being of individual sufferers, diminish health-related quality of life, increase healthcare costs, and reduce the individual's willingness or capacity to participate in work, family, and social activities (Dahlöf & Solomon, 2006; Diamond et al., 2007; IHS, 2004).

To minimize the pain and disability migraine produces, most migraine sufferers take various combinations of medications that address symptoms associated with their migraines. Although medications have provided relief for many, they provide only partial benefit. Limiting factors associated with medications for the treatment of migraine include inadequate response, adverse events such as headache recurrence and addiction, potential drug interactions, formulary restrictions, contraindications, high cost, and patient preference for a nonpharmacologic treatment (Lipton, Stewart, Diamond, S., Diamond, M. L., & Reed, 2001; Mathew & Tfelt-Hansen, 2006).

Limitations associated with symptomatic medications combined with the substantial social and economic consequences of migraine underscore the need to improve current approaches for managing migraine. Developing and evaluating novel treatments that are cost-effective and can be shown to reduce the impact of disability associated with migraine may be one of the best ways to optimize outcomes.

Nonpharmacologic therapies may reduce attack-related disability and the overall impact of migraine. In addition, nonpharmacologic therapies have been shown to enhance personal control of headache, reduce treatment costs, and sustain long-term improvements. Nonpharmacologic therapies may be particularly well-suited for individuals who are unable or unwilling to take drugs (e.g., those who are pregnant, nursing, or planning to become pregnant); who have an insufficient response to pharmacologic therapies, poor tolerance for medications, or with a history of frequent or excessive use of analgesics or acute medications (McGrath, Penzien, & Rains, 2006).

Despite empirical evidence demonstrating the effectiveness of nonpharmacologic therapies in producing clinically meaningful reductions in headache impact, they are rarely integrated into treatment strategies for managing migraine (McGrath et al., 2006). A variety of factors contribute to the underutilization of nonpharmacologic therapies in migraine management. As previously discussed, the paucity of research on nonpharmacologic therapies for the treatment of migraine has led many healthcare providers to overlook the value and cost-effectiveness of these therapies in migraine management.

Headache classification and migraines. Major headache groups are subdivided into types, subtypes, and subforms (IHS, 2004). For example, migraine is a primary headache that consists of one group (1. Migraine), one type (migraine), six subtypes (1.1 Migraine without aura, 1.2 Migraine with aura, 1.3 Childhood periodic syndromes that are commonly precursors of migraine, 1.4 Retinal migraine, 1.5 Complications of migraine, 1.6 Probable migraine), and 17 subforms (1.2.1 Typical aura with migraine headache, 1.2.2 Typical aura with non-migraine headache, 1.2.3 Familial hemiplegic migraine et al.; IHS, 2004).

Within the literature headache disorders are identified with varying degrees of specificity. For instance, migraine is commonly used as an umbrella term to encompass more than one type of migraine. At times, the precise migraine syndromes are identified, but oftentimes they are not. For this reason, this paper identified headache disorders with the degree of specificity that was consistent with the literature.

In addition, most studies have examined MWOA and migraine with aura (MWA) together, with the exception of studies on migraine mechanisms and genetic studies (Olesen & Goadsby, 2006). Considerably less research has examined MWOA individually. Consequently, it was not possible to review all aspects of MWOA separately.

Table 1

ICHD-II diagnostic criteria for MWOA

A. At least five attacks fulfilling criteria B–D
B. Headache attacks lasting 4–72 hours (untreated or unsuccessfully treated)
C. Headache has at least two of the following characteristics:
    1. Unilateral location
    2. Pulsating quality
    3. Moderate or severe pain intensity
    4. Aggravation by or causing avoidance of routine physical activity (e.g. walking or climbing stairs)
D. During headache at least one of the following:
    1. Nausea and/or vomiting
    2. Photophobia and phonophobia
E. Not attributed to another disorder

Source: IHS, 2004.

Phases of a migraine attack. Four distinct phases of a migraine attack have been identified: premonitory symptoms, sensory phase, pain phase, and postdrome (Zagami & Bahra, 2006).

The first phase of a migraine attack is characterized by premonitory symptoms. Premonitory symptoms are symptoms that indicate disease onset. Premonitory symptoms for migraine are physiological and emotional. Typical physiological premonitory symptoms include frequent urination, water retention, constipation, nausea, repetitive yawning, slurred speech, pallor, visceral dilation, blurred vision, neck stiffness, muscle tension, photophobia, and phonophobia. Typical emotional premonitory symptoms include cravings for particular foods, increased appetite, fatigue, insomnia, hypoactivity, hyperactivity, anxiety, euphoria, irritability, difficulty concentrating, depression, and other less typical symptoms. Premonitory symptoms occur in various combinations and typically precede the attack by 2 to 48 hours (IHS, 2004; Parsons, 2006; Sacks, 1992; Zagami & Bahra, 2006).

The second phase of a migraine attack is the sensory phase. The sensory phase is characterized by neurological symptoms called auras (Cutrer & Olesen, 2006). Auras are fully reversible "focal neurological symptoms that usually precede and sometimes accompany the headache" (IHS, 2004, p. 24). Migraine auras include visual, sensory, language, and motor disturbances. The most common type of migraine aura is visual aura (IHS, 2004). Visual auras are "the manifestations of focal and cerebral dysfunction" (IHS, 2004). Visual migraine auras include scotomas ("a spot in the visual field in which vision is absent or distorted"; Merriam-Webster, 2005, p. 1114), diffuse blurring, distortions, hallucinations, scintillations (bright visual hallucinations that fluctuate in intensity; IHS, 2004), loss of vision, flickering lights, and spots or lines (Cutrer & Olesen, 2006; IHS, 2004). The following types of aura are experienced in descending order of frequency: sensory, language, and motor disturbances. Sensory symptoms may include paresthesia ("a sensation of pricking, tingling, or creeping on the skin that has no objective cause"; Merriam-Webster, 2005, p. 901), tingling, numbness, and a loss of awareness of a body part (Cutrer & Olesen, 2006; IHS, 2004). Language symptoms may include aphasia ("loss or impairment of the power to use or comprehend words"; Merriam-Webster, 2005, p. 57) and dysarthria ("difficulty in articulating words due to disease in the central nervous system"; Merriam-Webster, 2005, p. 389). Motor symptoms may include motor weakness and paresis ("slight or partial paralysis"; Merriam-Webster, 2005, p. 901). Migraine auras develop gradually, over 5 to 20 minutes, and last for less than 60 minutes (IHS, 2004).

The third phase of a migraine attack is the pain phase. The pain phase is usually the most painful and debilitating part of a migraine attack. Prior to the onset of the pain phase individuals often experience a state of dread or depression. Headache is generally considered the hallmark characteristic of the pain phase. The quality of headache is commonly described as stabbing, pressing, bursting, throbbing, pulsating, icepick pains or jabs and stabs, and "momentary sharp shooting pains in various parts of the head, including the eye" (Zagami & Bahra, 2006, p. 402). Location of headache is usually hemicranial (i.e., located on either the right or left side of the head, does not cross the midline; IHS, 2004). Location of headache may also be bilateral (i.e., frontal temporal or occipital only; IHS, 2004) or generalized (i.e., affecting the whole head). Headache is a symptom of all forms of migraine with two exceptions: typical aura with nonmigraine headache and typical aura without headache (Cutrer & Olesen, 2006; IHS, 2004). Although headache is generally considered the hallmark characteristic of the pain phase, it is never the sole symptom. Accompanying symptoms may include photophobia, phonophobia, abdominal pain, vomiting, tenderness or pain in or behind the eyeball, bloodshot eyes, sinus discomfort, fever, constipation, diarrhea, increased urination, swollen face, and cold hands or feet. Accompanying symptoms occur in various combinations and may

change from one attack to the next. The pain phase usually lasts for several hours to several days and sometimes weeks (IHS, 2004; Olesen & Dodick, 2006; Sacks, 1992; Zagami & Bahra, 2006).

The final phase of a migraine attack is postdrome. Postdrome is commonly referred to as the "migraine hangover" because individuals often remain symptomatic even after the headache and accompanying symptoms have subsided. Typical postdrome symptoms include mood changes, fatigue, muscular weakness, and reduced appetite. Resolution of these and other less typical postdrome symptoms is usually gradual and often achieved by taking various combinations of symptomatic medication, vomiting, bed rest, sleep, and retreating to a dark and quiet room. Postdrome usually lasts for several hours to several days (IHS, 2004; Zagami & Bahra, 2006).

Hemoencephalography. Hemoencephalography (HEG) is a form of neurofeedback (NF) that was invented by Hershel Toomim in 1995 and makes use of light in the range of red to infrared wavelengths to access and monitor blood flow changes in the prefrontal cortex (Toomim & Carmen, 2009). Infrared emissions are electromagnetic radiation with wavelengths longer than visible light but shorter than radio waves. Any object that has a temperature above absolute zero emits infrared emissions. Emissions from tissue in the brain "reflect the level of metabolic activity which, in turn, is responsive to oxygen levels, neurotransmitter levels, blood flow, and other variables" (Freides & Aberbach, 2005, p. 55). The primary objective of HEG NF is to train increases in neural activity in the prefrontal cortex by "inducing increases in cerebral blood flow" (Toomim & Carmen, 2009, p. 190).

HEG NF is typically provided to sites in the prefrontal cortex, commonly referred to as the executive center of the brain, which consists of Brodmann Areas 9, 10, 11, 12, 44, 45, 46, and 47. The primary function of the prefrontal cortex is to regulate complex cognitive, emotional, and behavioral functioning (Pliszka, 2003). HEG NF is typically provided for brain activity in the region of Braodmann Area 10 or adjacent areas.

HEG depends on changes in characteristics of blood (oxygen, temperature) that are correlated with changes in brain activity and metabolism. The color and temperature of cerebral blood flow provides information about neuronal activity. The brain requires oxygen and glucose to perform activities. Metabolically active areas of the brain require more oxygen and glucose. As oxygenated blood infuses the tissue based on use-dependent demand, the brain gets redder, and as the glucose and other bloodborne nutrients are metabolized it gets warmer. Consequently, metabolically active areas of the brain are redder and warmer, whereas metabolically inactive areas of the brain are purple and cooler (Toomim & Carmen, 2009). HEG measurements of oxygen and temperature can be used to operantly shape increased brain activity.

HEG is designed to train increases in the brain's ability to regulate its physiological activity so that maladaptive patterns of brain function can be better regulated and result in reduced symptoms and enhanced performance. The primary objective of HEG training is to improve the control and management of symptoms by perturbing older more stable patterns of physiologic function.

HEG has demonstrated efficacy in improving treatment outcomes in a plethora of neurologic conditions. These include attention-deficit/hyperactivity disorder (ADHD), autistic spectrum disorders, bipolar disorder, traumatic brain injury (TBI), age-related memory loss, migraine and other headaches, epilepsy, Tourette's disorder, obsessive compulsive disorder (OCD), stroke, depression, schizophrenia, and toxic encephalopathy (Toomim & Carmen, 2009). The central mechanisms underlying the conditions noted above include malfunctioning brain modules and networks, and difficulties with arousal and inhibition. Specifically, these conditions are hypothesized to be caused by an excessive response by the brain in terms of the rate and magnitude to relatively minor stimuli (Toomim & Carmen, 2009).

Research Questions. This study examined the following research questions:

1) Do participants experience a statistically significant reduction in the global impact of headache-related disability, as evidenced by the reduction of HIT-6 scores after six and 10 treatment sessions with pIR HEG?
2) Do participants experience a statistically significant reduction in the functional impact of headache-related disability, as evidenced by the reduction of MIDAS questionnaire scores after six and 10 treatment sessions with pIR HEG?
3) Do participants experience a statistically significant reduction in the frequency of attacks of MWOA, as evidenced by the reduction of MIDAS subscale A scores after

six and 10 treatment sessions with pIR HEG?

4) Do participants experience a statistically significant reduction in the severity of attacks of MWOA, as evidenced by the reduction of MIDAS subscale B scores after six and 10 treatment sessions with pIR HEG?

Method

This study implemented a quasi-experimental research design, which involves nonrandom assignment of participants to the treatment and does not manipulate the presence or absences of the independent variable (i.e., HEG NF). According to Heppner, Kivlighan, and Wampold (1999) quasi-experimental designs "can be especially useful in the evaluation of new and innovative programs" (p. 172) and are appropriate in clinical settings when withholding treatment from participants (placebo) is unethical. The same measures were employed at three time points: baseline (Pretest), after the sixth treatment session (Midtreatment), and after the tenth treatment session (Posttest); thereby utilizing a repeated-measures research design. This study was approved by the St. Mary's university Institutional Review Board.

Participants

Adults (28 women, 3 men, *M* age = 38.65 years, range: 20–65 years) who met ICHD-II (IHS, 2004) diagnostic criteria for MWOA were recruited from three cities in Texas: San Antonio, Schertz, and Austin. Participants were recruited through flyers posted at counseling centers, an online advertisement, and referrals from healthcare professionals (physicians, neurologists, and counselors). Eligible participants were 18 years and older, fulfilled ICHD-II diagnostic criteria for MWOA, and were under the continual care of a physician or neurologist for MWOA throughout the study. Individuals who had received a previous diagnosis of a secondary headache disorder, evidence of medication overuse or abuse, consumption of illegal drugs or current drug use, and concurrent participation in other research projects were excluded.

In addition, participants had to have a baseline HIT-6 score of ≥ 56, indicating that migraines were having a substantial to very severe headache impact. All participants were exposed to the intervention. Table 2 depicts mean demographic information regarding the entire sample population.

Table 2

Demographic Characteristics of Participants

Characteristic	*n*	%
Self-identity		
Caucasian	23	74
African American	1	3
Hispanic or Latino	5	16
Other	2	6
Relationship status		
Single, never married	8	25
In a committed relationship	2	6
Cohabitating	1	3
Married	16	51
Divorced but remarried	2	6
Divorced	1	3
Engaged	1	3
Education level completed		
Some college	5	16
Associate degree	1	3
Bachelor's degree	14	45
Master's degree	9	29
PhD	1	3
J.D.	1	3
Family history of migraine		
Yes	23	74
No	2	6
Unsure	6	19

Note. *N* = 31.

Table 3 depicts Means and Standard Deviations for Age of Onset and Years Lived with MWOA.

Table 3

Means and Standard Deviations for Age of Onset and Years Lived with MWOA

			95% CI	
Variable	*M*	*SD*	LL	UL
Age of onset of MWOA	16.42	7.65	13.62	19.22
Years lived with MWOA	22.90	12.96	18.15	27.66

Note. *N* = 31. CI = confidence interval; LL = lower limit; UL = upper limit.

Role of the Researcher

The principal investigator administered the demographic questionnaire, headache instruments, and the treatment, as well as oversaw all aspects of the study. The principal investigator had previously received formal training in neurofeedback from a clinician with board certification in neurofeedback from the Biofeedback Certification International Alliance (BCIA). In addition, the principal investigator received supervision from Jeffrey Carmen, who was the subject matter expert on pIR HEG, prior to and during the study.

Measures

HIT-6. The HIT-6 was developed by an international team of headache experts and psychometricians and is intended to be used by persons 18 years and older. The HIT-6 is among the most widely used instruments for assessing the impact of headaches and headache treatments and is useful for screening and monitoring changes in headache impact over time. The HIT-6 is a paper-form survey that measures the global impact of headache-related disability on the individual sufferer's life. Specifically, the HIT-6 measures the impact of headaches on the level of functioning and the well-being of the respondent. The HIT-6 has been used in scholarly research, clinical research and practice, disease management, population monitoring, and risk assessment (Dahlöf & Solomon, 2006; Kosinski et al., 2003; Nachit-Ouinekh et al., 2005).

The HIT-6 is a six-item self-administered questionnaire that assesses six domains of headache impact: cognitive functioning, psychological distress, pain, role-functioning, social functioning, and vitality. Response options for each item are never, rarely, sometimes, very often, and always. Response options are scored as: *Never* = 6; *Rarely* = 8; *Sometimes* = 10; *Very often* = 11; and *Always* = 13 (Kosinski et al., 2003). Recall period for all items is the previous 4 weeks (Bjorner, Kosinski, & Ware, 2003b; Gandek, Alacoque, Uzun, Andrew-Hobbs, & Davis, 2003; Kosinski et al., 2003; Nachit-Ouinekh et al., 2005). The HIT-6 score is derived as the sum of the six items with minimum and maximum possible values of 36 and 78, respectively. Higher scores are indicative of greater headache impact. HIT-6 scores are rated on a 4-point grading system. The 4-point grading system for the HIT-6 total score is as follows: grade 1: Little to no impact (score ≤ 49); grade 2: Some impact (score = 50–55); grade 3: Substantial impact (score = 56–59); and grade 4: Very severe impact (score ≥ 60).

The HIT-6 has demonstrated evidence of reliability and validity. The internal consistency and test-retest reliability estimates were .89 and .80, respectively (Kosinski et al., 2003).

MIDAS questionnaire. The MIDAS questionnaire was based in part on input from an expert advisory committee and the Headache Impact Questionnaire (Stewart, Lipton, & Kolodner, 2003; Stewart, Lipton, Kolodner, et al., 1999). Among the most widely used instruments for assessing the impact of headache-related disability, the MIDAS questionnaire was used to measure the functional impact of headache-related disability. The MIDAS questionnaire assesses lost time because of headache in three domains of activity: work for pay or school, household work or chores, and family, social, and leisure activities (Stewart, Lipton, Kolodner, et al., 1999; Stewart, Lipton, Whyte, et al., 1999).

The MIDAS questionnaire is a five-item self-administered questionnaire that assesses time lost for headache in work for pay or school, household work or chores, and family, social, and leisure activities. Responses for each item are scaled in units of the number of days missed and the number of days activity was reduced by 50% or more for headache. The first three items ask respondents about the number of days they missed for headache in work for pay or school; household work or chores; and family, social, and leisure activities. The next

two items ask respondents about the number of days their productivity was reduced by 50% or more for headache in work for pay or school and household work or chores (Bjorner, Kosinski, & Ware, 2003a; Stewart, Lipton, & Kolodner, 2003; Stewart, Lipton, Whyte, et al., 1999).

The MIDAS score is derived as the sum of the five items, with minimum and maximum possible values of 0 and 91, respectively. Higher scores are indicative of greater headache impact. MIDAS scores are rated on a 4-point grading system. The 4-point grading system for the MIDAS score is as follows: grade I: Little or no disability (score = 0–5); grade II: Mild disability (score = 6–10); grade III: Moderate disability (score = 11–20); and grade IV: Severe disability (score ≥ 21).

Two additional items, MIDAS subscale questions A and B, assess the frequency and the severity of headache attacks, respectively, but these items do not contribute to the MIDAS score. The frequency of attacks is measured in units of the number of days that headache was present. The severity of attacks is ranked on a 10-point scale ranging from 0 (*no pain at all*) to 10 (*pain as bad as it can be*). Recall period for all items is the previous 3 months (Dahlöf & Solomon, 2006; Stewart, Lipton, & Kolodner, 2003; Stewart, Lipton, Whyte, et al., 1999).

The MIDAS questionnaire has demonstrated evidence of reliability and validity (Stewart, Lipton, Kolodner, et al., 1999; Stewart, Lipton, Whyte, et al., 1999). For the individual MIDAS items, the test-retest Spearman correlation coefficient ranged from .67 to .73 ($p < .001$; Stewart, Lipton, Kolodner, et al., 1999); the test-retest Pearson correlation coefficient ranged from .60 to .70 ($p < .001$). For the MIDAS score the test-retest correlations were high (Spearman correlation coefficient = .84; Pearson correlation coefficient = .75, $p < .001$; Stewart, Lipton, Kolodner, et al., 1999). Cronbach's alpha was high ($\alpha = .83$, $p < .001$; Stewart, Lipton, Kolodner, et al., 1999).

Both the HIT-6 and the MIDAS questionnaire are brief, comprehensive, and easy to interpret while providing meaningful scores. In addition, both instruments are sensitive enough to reflect changes in headache impact over time and may be used as outcome measures to monitor the effectiveness of a treatment (Dahlöf & Solomon, 2006; Stewart, Lipton, Kolodner, et al., 1999; Stewart, Lipton, Kolodner, Sawyer, et al., 2000). Although the HIT-6 and the MIDAS questionnaire quantify the impact of headache-related disability, these instruments differ in content and design. First, the HIT-6 assesses multiple dimensions of headache impact (global disability), whereas the MIDAS questionnaire assesses one dimension of headache impact (functional disability). Second, the HIT-6 includes information on fatigue, cognition, and mental distress; the MIDAS questionnaire includes information on attack frequency and attack severity. Third, these instruments differ in response format (5-point response scale vs. number of missed days due to headache, respectively) and the time interval assessed (4 weeks vs. 3 months, respectively; Bjorner et al., 2003a; Magnoux, Freeman, & Zlotnik, 2007).

Finally, correlations between the HIT-6 and the MIDAS questionnaire ranged between .42 and .44, suggesting that these instruments are weakly correlated (assess different dimensions of headache-related disability), and therefore should not be used interchangeably (Magnoux et al., 2007). The rationale for using these instruments together was to gain a more comprehensive picture of headache-related disability.

Demographic questionnaire. The demographic questionnaire was designed to elicit information about participants' age, gender, ethnicity, relationship status, occupation, education level, family history, medical history, age of onset for MWOA, and the number of years lived with MWOA. An additional item asks respondents about the manner in which he or she learned about the study. The demographic questionnaire was created by the principal investigator for the purpose of this research project.

Materials

This study used a notebook computer (HP Pavillion dv7.1245dx), the EZPIR system (Jeff Carmen; Manlius, NY), and DVDs. The EZPIR system has two major components: the headset and encoder hardware, and BioEra software (Proatech LLC, www.proatech.com; version 2.3.109). The headset is a small black box that houses dual overlapping sensors. The sensors detect infrared radiation within the 7 to 14 micron range and have a rectangular field of view of approximately 1.5 inches (in height) by 2 inches (in diameter) with a response speed of 30 ms (Carmen, 2004; Toomim & Carmen, 2009). As shown in Figure 1, the headset is attached to an adjustable elastic headband which is secured around the top of the individual's head and the headset is positioned at Fpz (i.e., the center of the forehead). The headset connects to an encoder. The encoder is a rectangular box that converts the

acquired signal (analog signal) into a digital USB signal, and then sends the digitized signal to the computer where it is processed by the BioEra software. To ensure the integrity of the pIR HEG system and to avoid potential interference with the software, following the installation of the software, the wireless assistant was disabled and no additional programs were installed on the notebook computer.

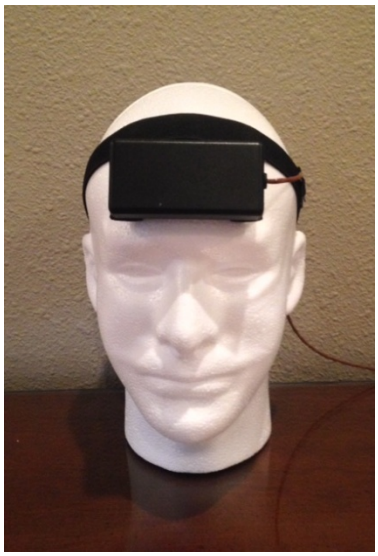

Figure 1. pIR HEG Headset.

Procedure

Upon referral, potential participants underwent a pre-screening to assess their initial eligibility and their interest in the study. At this time, the principal investigator answered any questions about the study protocols. This screening took place over the telephone and took approximately 10 minutes to complete. Those who did not qualify were excluded, thanked for their time, and given referral information for alternative treatments for MWOA.

Potential participants scheduled a meeting with the principal investigator and were asked to plan on spending 1 hour. At the initial meeting, the principal investigator provided a cover letter, discussed confidentiality, and answered any remaining questions about the study protocols. Informed consent was obtained from each participant in accordance with the approval from St. Mary's Institutional Review Board.

After informed consent was obtained, participants completed the HIT-6 to determine whether they qualified for continued participation in this research project. Participants needed a baseline HIT-6 score of ≥ 56 to be eligible for continued participation. Participants with a baseline HIT-6 score of ≤ 55 were excluded. The HIT-6 took approximately 5 minutes to complete. Qualified participants completed a demographic questionnaire and the MIDAS questionnaire, and then began treatment. The MIDAS questionnaire and the demographic questionnaire took approximately 10 minutes to complete.

All participants received the treatment. The treatment consisted of administration pIR HEG. The treatment was conducted in accordance with clinical practice guidelines for administering pIR HEG in individuals with migraine. The treatment consisted of 10 sessions delivered, on average, 1 week apart. Once a week was the planned session frequency, however, due to scheduling conflicts (e.g., child care and work obligations) sessions were sometimes less frequent than once a week. On average, the intersession interval was 1.5 weeks. Sessions took place at one of three clinical settings: the Family Life Center at St. Mary's University, the Schertz Family Support Center, or the principal investigator's private practice in Austin, TX. For all participants, the first three sessions took place in the morning. The remaining seven sessions took place at various times throughout the day. The location and the time of the sessions were scheduled at the convenience of the participant. The duration of each treatment session was approximately 1 hour.

Part of the treatment involved the participants watching a movie on the screen of the notebook computer. Participants were given the option to bring in a DVD or to select a DVD from the principal investigator's personal collection. Participants were instructed to select movies that would engage their emotions and draw them into the plot so that they lost awareness of self, the room, etc., and to avoid movies that elicit shock or fear.

Each session proceeded as follows. First, prior to executing the treatment, participants were asked about their headache activity, sleep activity, and medication usage since their last session. This assessment took approximately 5 minutes to complete. Second, the EZPIR headband was secured around the top of the head and the headset was positioned at Fpz (i.e., center of the forehead). Third, the BioEra program was opened. Fourth, the DVD was inserted into the optical disc drive of the notebook computer. Fifth, the BioEra program was started and the play mode of the DVD was set to the continuous play mode for 5 min. After the first 5 min,

the play mode of the DVD was changed to the auto threshold mode. At this time, participants were instructed to try to maintain a mental state that was simultaneously calm and focused. If the movie paused, the participant was instructed to relax and to focus. The length of time the system remained at the auto threshold mode varied from 10 to 25 minutes and was determined by the session number and the participant's response to the treatment. For the first three sessions, time at the auto threshold mode was limited to 10 min. For the remaining seven sessions, the length of time at the auto threshold mode was limited to 25 min.

Sessions were discontinued for the following reasons: (a) the participant developed a headache, (b) the participant became fatigued, (c) the participant experienced physical or emotional discomfort, (d) rapid fluctuations in the pIR signal were observed, or (e) the pIR signal dropped below the auto threshold level five times. Discontinuation occurred on average two times per participant.

Participants completed the HIT-6 and the MIDAS questionnaire on three occasions: baseline (Pretest), after the sixth treatment session (Midtreatment), and after the tenth treatment session (Posttest). Following completion of data collection, the principal investigator conducted quantitative analyses to assess changes in the impact headache-related disability, attack frequency, and attack severity.

Data Analysis

Data collected from the demographic questionnaire, HIT-6, and MIDAS questionnaire were entered into a dataset using SPSS (IBM Corp., Armonk, NY; version 21.0). First, descriptive statistics were conducted to explore the frequencies and percentages of the demographic variables among the participants.

Second, a one-way within-subjects multivariate analysis of variance (MANOVA) was conducted to determine whether pIR HEG resulted in a significant multivariate effect. Significant multivariate effects were followed up with corresponding univariate tests. Significant interactions were followed up with pairwise comparisons to determine whether the intervention resulted in a significant change on the relevant dependent measures from Pretest to Midtreatment, Midtreatment to Posttest, and Pretest to Posttest. The headache instruments (i.e., HIT-6 and MIDAS questionnaire) are the repeated measures and pIR HEG is the intervention.

Results

A one-way MANOVA was conducted to evaluate the sample means for scores on the HIT-6, MIDAS, MIDAS subscale A, and MIDAS subscale B at three time points for the 10-week protocol of pIR HEG. The within-subjects factor was the time point and included three levels: pretreatment (baseline), midtreatment (after six treatment sessions), and posttreatment (after 10 treatment sessions). The four dependent variables were HIT-6, MIDAS, MIDAS subscale A, and MIDAS subscale B mean scores. Significant differences were found among the three time points on the dependent measures, Wilks's $\Lambda = .45$, $F(8, 114) = 7.00$, $p < .05$. The multivariate η^2 of .33 indicated a strong relationship between time point and the dependent variables. Table 4 contains the means and the standard deviations on the dependent variables for the three time points.

Table 4

Means and Standard Deviations on HIT-6, MIDAS, MIDAS subscale A, and MIDAS subscale B Scores for the Three Time Points

Measure	Pretest		Midtreatment		Posttest	
Mean Scores	*M*	*SD*	*M*	*SD*	*M*	*SD*
HIT-6	64.32	4.58	58.19	6.41	55.87	6.36
MIDAS	33.36	37.26	23.84	29.08	16.32	20.79
MIDAS_A	25.58	26.49	22.87	24.08	17.26	18.52
MIDAS_B	6.94	1.18	5.42	1.67	5.13	1.28

Note. $N = 31$. HIT-6 = Headache Impact Test-6; MIDAS = Migraine Disability Assessment; MIDAS_A = Migraine Disability Assessment subscale A; MIDAS_B = Migraine Disability Assessment subscale B.

Analyses of variance (ANOVA) on each of the dependent variables were conducted as follow-up tests to the MANOVA. The Bonferroni method was used to control for familywise error across the four tests. Therefore, alpha was set at .05 divided by 4 or .0125, for each test. Three of the ANOVAs were significant: the HIT-6 scores, $F(2, 60) = 24.63$, $p < .001$, $\eta^2 = .45$; the MIDAS scores, $F(1.56, 51.59) = 8.39$, $p = .002$, $\eta^2 = .22$; and the MIDAS subscale B scores, $F(2, 60) = 17.33$, $p < .001$, $\eta^2 = .37$. The univariate ANOVA for the MIDAS subscale A scores was nonsignificant, $F(1.38, 41.34) = 2.30$, $p = .129$, $\eta^2 = .07$. Table 5 contains the results of the univariate ANOVAs for the HIT-6, MIDAS, MIDAS subscale A, and MIDAS subscale B scores.

Table 5

One-Way Within-subjects Analyses of Variance for HIT-6, MIDAS, MIDAS subscale A, and MIDAS subscale B Scores

Measure	*MS*	*F*	*p*	η^2
HIT-6	591.01	24.63	< .001*	.45
MIDAS	2258.59	8.39	.002*	.22
MIDAS_A	558.58	2.30	.129	.07
MIDAS_B	29.17	17.33	< .001*	.37

Note. $N = 31$. η^2 = effect size. $df(8, 114)$. *alpha set at $p < .0125$ to determine significance.

Post hoc pairwise comparisons for the univariate ANOVAs for the HIT-6, MIDAS, and MIDAS subscale B scores were then conducted to evaluate if there was a difference in HIT-6, MIDAS, and MIDAS subscale B mean scores across the three time points. The Holm's sequential Bonferroni approach (Holm, 1979) was used to control for familywise error across the three tests. Therefore, each pairwise comparison was tested at the alpha level of .0125 divided by 3, or .004.

For the HIT-6 scores, significant differences were found among two of the time points: from pretest to midtreatment, and from pretest to posttest. The greatest reduction in HIT-6 scores was from pretest to posttest (8.45 points, $SE = 1.46$, $p < .001$, LL = 2.36, UL = 12.94). The next greatest reduction in HIT-6 scores was found from pretest to midtreatment (6.13 points, $SE = 2.36$, $p < .001$, LL = 2.32, UL = 9.94). However, there was no significant difference in the HIT-6 mean scores from midtreatment to posttest. For the MIDAS scores, significant differences were found at one time point, from pretest to posttest 17.03, $SE = 4.42$, $p = .002$, LL = 3.39, UL = 30.67. No significant differences were found between pretest and midtreatment, or between midtreatment and posttest. For the MIDAS subscale B scores, significant differences were found at two of the time points, from pretest to midtreatment, and from pretest to posttest. The greatest reduction in MIDAS subscale B scores was from pretest to posttest 1.81, $SE = .30$, $p < .001$, LL = .87, UL = 2.74. The next greatest reduction in MIDAS subscale B scores was from pretest to midtreatment, 1.52, $SE = .37$, $p = .001$, LL = .38, UL = 2.65. No significant differences were found between midtreatment and posttest.

The results indicated, in the sample population, a significant reduction in the HIT-6 mean scores (global impact of headache-related disability) from pretest to the midtreatment, and from pretest to posttest following in a 10-week protocol of pIR HEG. Results also indicated a significant reduction in the MIDAS mean scores (functional impact of headache-related disability) from pretest to posttest. While the MIDAS mean scores changes did not yield significance for pretest to the sixth treatment session, or for the sixth treatment session to posttest, results indicated a significant reduction in the MIDAS subscale B mean scores (severity of attacks) from pretest to midtreatment, and from pretest to posttest. Table 6 presents the 99% confidence intervals for the pairwise comparisons.

Table 6

Results of 99% Confidence Intervals of Pairwise Differences in Mean Changes in HIT-6, MIDAS, and MIDAS subscale B Scores among Three Time Points

Variable	Time Point	Time Point	Mean Difference
HIT-6			
	Pretest	Midtreatment	6.13*
	Pretest	Posttest	8.45*
	Midtreatment	Posttest	2.32
MIDAS			
	Pretest	Midtreatment	9.52
	Pretest	Posttest	17.03*
	Midtreatment	Posttreatment	7.52
MIDAS_B			
	Pretest	Midtreatment	1.52*
	Pretest	Posttest	1.81*
	Midtreatment	Posttest	0.29

Note. N = 31. *p < .004. Pretest = baseline; Follow-up = after 6 treatment sessions; Posttest = after 10 treatment sessions.

Discussion

This study found a significant reduction in the global impact of headache-related disability (HIT-6 scores) from pretest to midtreatment, and from posttest. Results indicate a significant reduction in the functional impact of headache-related disability (MIDAS scores) from pretest to posttest. There were no significant differences in attack frequency (MIDAS subscale A scores) across the three time points. However, results indicated a significant reduction in attack severity (MIDAS subscale B scores) from pretest to midtreatment, and from pretest to posttest.

This study represents an important and unique contribution to the literature on nonpharmacologic interventions for the treatment of migraine in a number of respects. First, the current study included a sample that was more homogenous than that in any previously conducted research (cf. Carmen, 2004). Second, treatment was standardized for all subjects to 10 weeks, and limited to pIR HEG alone. Third, this research is among the first to use empirically validated assessments of headache impact (HIT-6, MIDAS Questionnaire) and to include assessments at three time points (baseline, after six treatment sessions, and after 10 treatment sessions).

Like Carmen's case series, this study showed reduction in headache severity. In the current 10-week treatment, headache frequency did not decline, in keeping with Carmen's report that frequency of headache occurred for some subjects only months after reduction in pain severity (Carmen, 2004). Whereas Carmen's positive case series provided both pIR HEG, but also other methods such as psychotherapy as applicable, the present study found good results using Carmen's pIR HEG system alone.

Findings from this study should be interpreted with caution because of several limitations. First, this study focused on a sample population with unique characteristics. This sample was comprised of adults with the migraine subtype MWOA and whose baseline HIT-6 scores indicated that headache impact was substantial to very severe. Therefore, it does not reflect the full range of migraine sufferers. A more diverse sample may produce different results which may be more generalizable.

Second, while this study evaluated multiple outcome measures (i.e., the global impact of headache-related disability, the functional impact of headache-related disability, the severity of attacks, and the frequency of attacks), consideration could be given to additional outcome measures, including changes in medication usage (e.g., a reduction in medication usage), an assessment of whether participants maintained symptom reduction after completing the treatment, and changes in overall healthcare costs and utilization of doctor visits. It would be beneficial to this population if future studies included these additional research elements. Likewise, this study did not include a placebo or control group. A placebo controlled RCT could significantly enhance the findings of successful outcomes.

It would be beneficial to migraine sufferers if future research included a qualitative component. A qualitative component would provide a more comprehensive picture of the overall impact of migraine on the lives of individual sufferers and humanize a condition that is often treated with derision and disbelief.

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NeuroRegulation

Treating Postchemotherapy Symptoms with Neurofeedback

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Abstract

Treatment for cancer often involves surgery, chemotherapy, and/or radiation. As a result of these interventions, studies have found that patients often experience prolonged side effects posttreatment. This case study focuses on a 62-year-old woman who was diagnosed with breast cancer and underwent surgery and chemotherapy. The patient was treated with 30 sessions of neurofeedback over the course of 2 weeks. Utilizing a combination of three different neurofeedback protocols, the patient reported significant improvements in cognitive and physical functioning.

Keywords: neurofeedback; chemotherapy; cancer; case study

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Introduction

Treatment for cancer often involves surgery, chemotherapy, and/or radiation. A comprehensive cancer treatment protocol is often a combination of some or all of these modalities, each of which can produce significant unwanted side effects. Being under general anesthesia, especially for extended periods of time, affects the brain and brain function (Storrs, 2014). Additionally, a team of researchers at the University of Rochester Medical Center and Harvard Medical School have posited that a common chemotherapy drug known as 5-fluorouracil (5-FU) is responsible for what is commonly referred to as "chemo brain," which is associated with significant decay of healthy neurons even after the use of the drug has ceased (URMC, 2008). Fortunately, there might be a way to moderate the impact of these interventions for patients. This article will briefly review the effects of anesthesia and chemotherapy on the brain and then describe a successful case of neurofeedback treatment with a postsurgery, chemotherapy, and radiation therapy breast-cancer patient.

Chemotherapy

It is common knowledge that cancer patients treated with chemotherapy experience a variety of negative and generally unpleasant side effects that often include, but are not limited to, depression, anxiety, short-term memory loss, difficulty concentrating, not being able to think clearly, connect thoughts or concentrate on daily tasks, and, in extreme cases, seizures, vision loss, and even dementia (Bruno, Hadi Hosseini, & Kesler, 2012; McDonald & Saykin, 2013; Nokia, Anderson, & Shors, 2012; Raffa & Tallarida, 2010; Silverman & Davidson, 2009). In fact, a study conducted by researchers with the James P. Wilmot Cancer Center at the University of Rochester showed that upwards of 82% of breast cancer patients reported that they suffer from some form of cognitive impairment (Michaud, 2008). In addition to cognitive difficulties, patients commonly experience chemotherapy-induced peripheral neuropathy, a physically debilitating condition with a range of symptoms including numbness, tingling, complete loss of sensation, pain, extreme cold sensations, or heaviness to name a few (Kolb et al.,

2016; Tofthagen, Kip, Passmore, Loy, & Berry, 2016). These changes inhibit activities of daily living such as driving a car, eating with utensils, dressing, and even walking. The scientific community in general continues to acknowledge that many chemotherapy agents may have a negative impact on brain function in some cancer patients. Unfortunately, the precise mechanisms that cause the brain's dysfunction have not been identified and have been difficult to pinpoint.

The side effects of chemotherapy usually diminish over time. However, follow-up studies have shown that some patients experience deleterious effects long after the conclusion of their treatments (Jim et al., 2012). In some cases, 15–20% of women who were treated for breast cancer experienced persistent cognitive problems after chemotherapy treatment, and 50% of women in one study had not returned to their baseline levels of cognitive functioning one year after chemotherapy treatment (URMC, 2008). These researchers also remarked that since chemotherapy clearly degenerates functions in the central nervous system, and this drug is likely to be the standard of care for the foreseeable future, it is imperative that science find methods of moderating the negative effects imposed by its use.

Anesthesia

Many patients diagnosed with cancer undergo surgery, which frequently requires the use of an anesthesia. Symptoms of postoperative delirium, a state of serious confusion, and memory loss are often associated with being under anesthesia. In addition to hallucinations, delirious patients may forget why they are in the hospital, have trouble responding to questions, and speak in nonsensical sentences (Storrs, 2014).

The iatrogenic effects from anesthesia generally begin to dissipate after one or two days. However, studies in the past 4 years suggest that a high enough dose can in fact raise the risk of delirium after surgery (Storrs, 2014). Recent studies also indicate that the condition may be more damaging than previously believed. Delirium (which often includes confusion and disorientation) can last at least a few hours and require patients to stay one night or longer in the hospital. It is also more common after major surgeries, and recent research over the past several years has revived anesthesia as a potential culprit in delirium (Storrs, 2014). Deep anesthesia has also been linked to subtler but longer lasting cognitive problems. In fact, some physicians have indicated that the effects of anesthesia on the brain can last upwards of one year or longer, and older individuals are more likely to have longer lasting negative effects (Perouansky & Hemmings, 2009).

Neurofeedback & Chemotherapy

The use of neurofeedback to moderate side effects from chemotherapy is not a new inquiry (Alvarez, Meyer, Granoff, & Lundy, 2013). Additionally, neurofeedback has been used specifically to treat pain in cancer patients (Prinsloo, Gabel, Lyle, & Cohen, 2014). The nervous system's fundamental feature is its neuroplasticity, that is, its ability to adapt to changing environmental conditions. A recent investigation showed that neurofeedback can lead to changes in human cortical excitability and that neurofeedback creates positive changes in both the gray and white matter of the brain (Ghaziri et al., 2013). These researchers proposed that alterations in the brain's white matter might support cognitive enhancement. They also noted that there is evidence that myelination is still sensitive to experiences during adulthood, therefore suggesting that neurofeedback might also lead to increased myelination. As mentioned earlier, chemotherapy has been linked to degeneration of the neurons, so it naturally follows that neurofeedback could be of significant benefit to counteract such effects.

Patient Background

Tiffany (name changed) is a 62-year-old, divorced white female who was initially diagnosed with breast cancer in July 2011. She underwent a lumpectomy in the same month with follow-up treatments that included postsurgical chemotherapy (four treatments of "red Devil") and radiation therapy as a precautionary measure. Radiation therapy began 4 months after her diagnosis on her right side only and consisted of 26 daily sessions. She reportedly tolerated it well with a little numbing in her toes. Postsurgical report indicated no lymph nodes or surrounding tissue were cancerous.

Unfortunately, in March 2013, Tiffany was diagnosed with recurrence of breast cancer, in the same spot of the incision for the lumpectomy. Tiffany underwent a right mastectomy that same month. A different chemotherapy drug combining tomaxifin together with adriamycin, cytoxan, and taxol (ACT) chemotherapy was administered postsurgery. Tiffany immediately noticed numbness and pain in her fingertips, toes, feet, and lower leg and reported this right away. Tiffany reported very different,

worsening, and severe side effects from the chemotherapy including feeling tired and dehydration. Her blood work indicated that she had a low red blood count. The doctors attempted to mediate the side effects by altering her chemotherapy treatment, but she continued to have worsening and severe side effects. Tiffany decided to cease her chemotherapy treatments after four sessions. Six months after her recurrence of cancer, Tiffany had a left mastectomy and reconstructive surgery to create pockets for implants. She was under anesthesia for the duration of the 7-hr surgery. Six months later, and 1 year after her recurrence, she had a final surgery in which implants were placed in the pockets created during the previous surgery.

Tiffany's medical history also includes a diagnosis of Diabetes Type II, which is controlled through Metformin 500 mg daily. She had participated in a weight loss program, and her A1C dropped to below the diabetic number; her diabetes is now controlled through diet. However, Tiffany was informed that Metformin could be helpful in resisting the return of cancer so she continued to take one tablet daily. Although Tiffany has normal and stable blood pressure, she takes blood pressure medication as a result of her parental heart history. Tiffany also takes Crestor to control cholesterol. Tiffany was active until age 60, has never smoked, and reportedly drinks a glass of wine or two daily. Tiffany also reported having routine mammograms and two breast reductions in 2004 and 2007 due to breasts being fibrous and cystic. Tiffany was unable to drive a car and unable to perform routine work requirements and was eventually terminated from her employment.

Neurofeedback Treatment

Due to follow-up doctors' appointments, Tiffany was only able to devote 2 weeks to her neurofeedback treatment. The decision was made to provide treatment sessions twice per day and three times on weekend days in order to provide a total of 30 sessions within the timeframe. Tiffany arrived at the office for treatment midweek in the beginning of September 2013. Her presentation upon arrival included poor sleep, numbing in hands and arms, and her balance was limited and required her to walk with a cane. When standing, she had to hold onto a solid object to keep her balance. Before beginning her treatment, Tiffany was informed that the clinician expected she would experience significant improvements in sleep and cognitive functioning. It was also stated that there was a chance other symptom relief could occur through neurofeedback treatment. She agreed to participate in her treatment and for her results to be included in research.

In addition to her neurofeedback training, Tiffany was encouraged to use mental imagery regarding walking balance and increased feeling in hands and feet, and she was encouraged to practice diaphragmatic breathing multiple times per day. Tiffany was asked to give periodic verbal progress reports when she noticed any significant changes or improvements.

Tiffany was administered multiple quantitative electroencephalograms (qEEG) to measure her brain functions both pre- and postintervention. Several years before her treatment, qEEG data was collected solely because she was interested to learn about her brain. Pertaining to her neurofeedback treatment, Tiffany was administered a pretreatment qEEG at the beginning of her treatment in September, and two posttreatment qEEGs 1 month and 7 months after her neurofeedback treatment. The New Mind Center (Roswell, GA) qEEG analysis service was utilized for all of her qEEG assessments. A comparison of these brain maps at three time points (pretreatment, 2-month posttreatment, and 7-month follow-up) is presented in Figures 1 and 2.

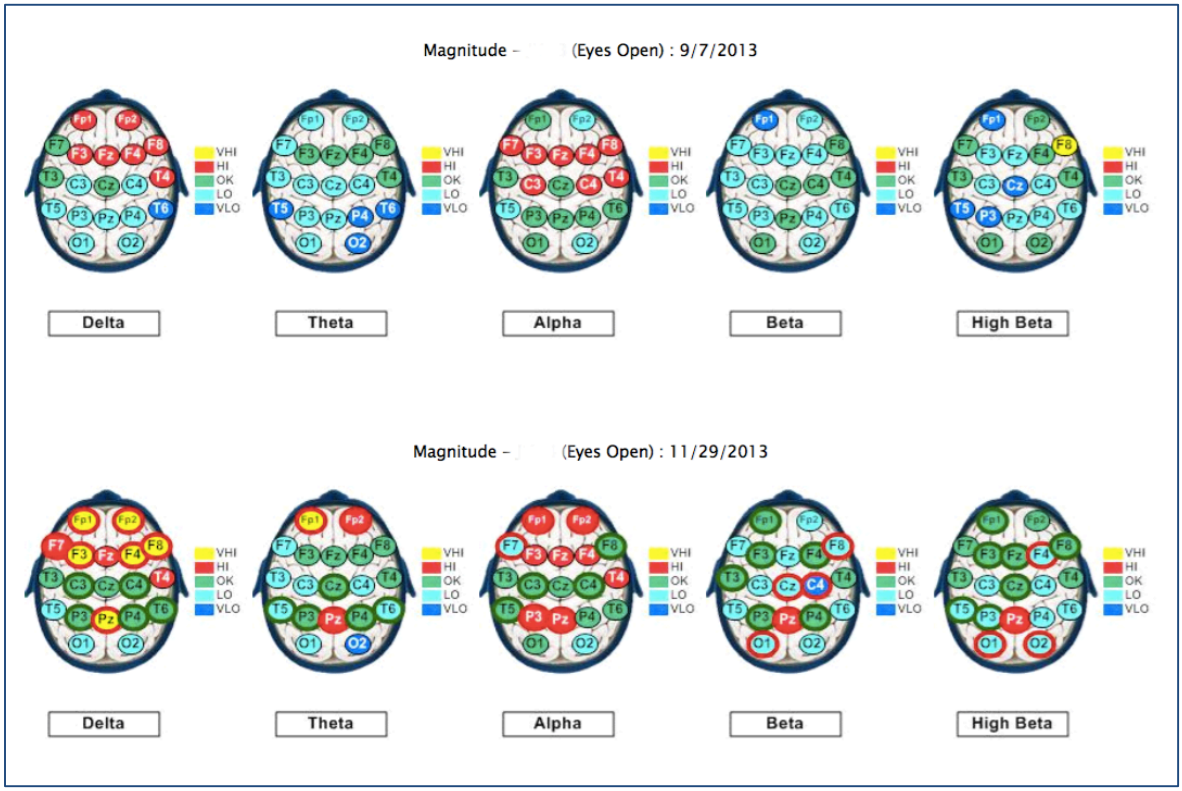

Figure 1. Comparison of qEEG results September (pretreatment) to November (2-month posttreatment). VHI = Very High, H = High, LO = Low, VLO = Very Low.

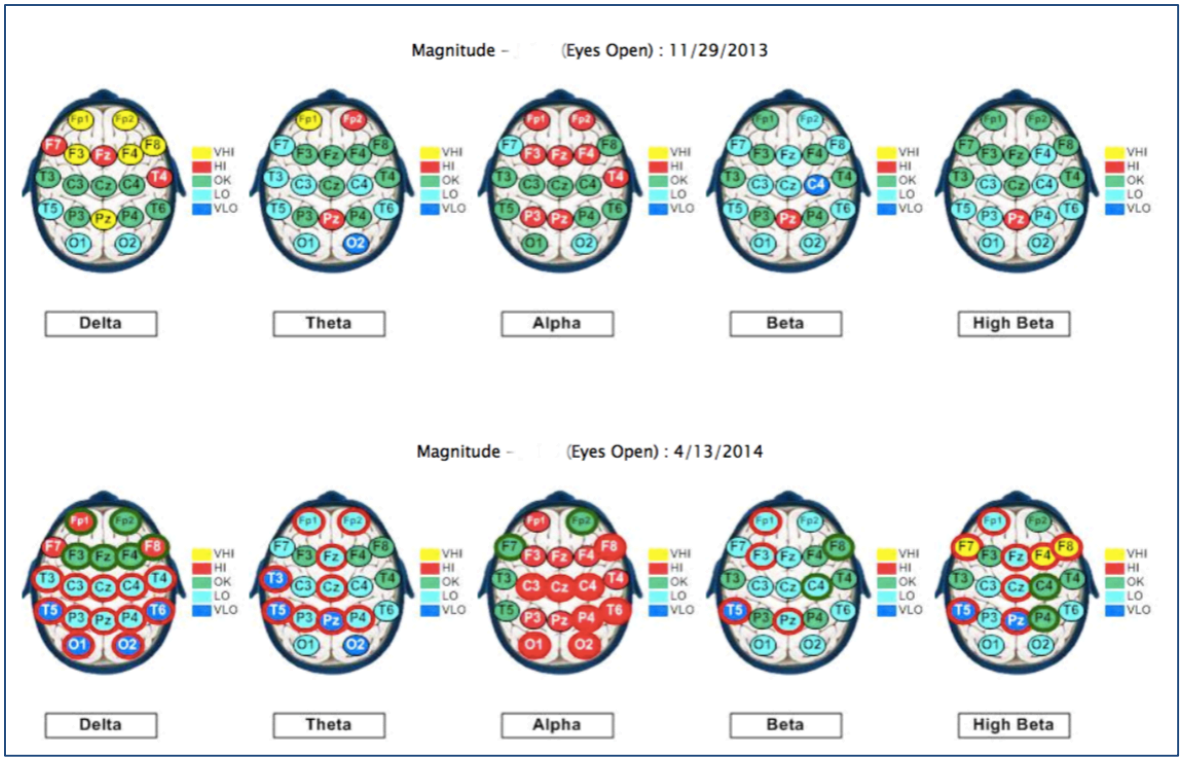

Figure 2. Comparison of qEEG results November (2-month posttreatment) to April (7-month follow-up). VHI = Very High, H = High, LO = Low, VLO = Very Low.

Tiffany began neurofeedback treatment the day after her arrival. Her protocols were derived from her qEEG data and are presented in Table 1. The clinician used an Atlantis I 4x4 system (BrainMaster Technologies, Inc, Bedford, OH). All protocols used a monopolar placement and were administered with the patient's eyes closed. Protocol 1 was single-channel training, and protocols 2 and 3 were two-channel trainings. A description of her course of treatment is presented in Table 2. She reported improvements in sleep and balance after the first day with continued gains by day two including increased sensations in her fingertips. She reported increased flexibility and sensation in her lower extremities during days three to four, and continued improvements in balance and range of motion in her feet through day seven. On the seventh day, she also reported being able to drive a car again. She reported similar gains in subsequent sessions with continuous improvements each day. These findings are supported by data from her pre and post brain maps.

The qEEG analysis service used in this case provides multiple metrics including magnitude, dominant frequency, coherence, and asymmetry are for each qEEG. For purposes of this case for which two-channel magnitude training protocols were used, and due to limited space, only changes in magnitude are presented in Figures 1 and 2. As the comparisons illustrate, the brain does not always heal by moving towards the norm. Often the brain's reorganization results in increases or decreases in magnitude yet the patient reports continued improvement as illustrated in Table 2 below.

Table 1

Neurofeedback Protocols Used During Training

Electrode Site	Inhibit Hz	Reward Hz	Inhibit Hz
Protocol 1			
Cz	2–10	13–15	16–30
Protocol 2			
C3	2–10	13–15	21–30
C4	2–7	13–15	21–30
Protocol 3			
T3	2–12	15–20	
T4		13–15	16–30

Table 2

Course of Treatment

Day #	Date	# of Sessions	Protocols	Observations
1	Sep 5	2	1, 2	Improved sleep and balance
2	Sep 6	2	1, 2	Improved sleep and balance, more energy, increased sensations in fingertips
3	Sep 7	3	2, 3	Could move feet up and down and also bend feet tippy toe which couldn't do before
4	Sep 8	3	2, 3	Felt a sensation (not painful) from mid body down to her feet during protocol three
5	Sep 9	2	1, 3	Better balance and walking a little better, better range of motion in feet
6	Sep 10	2	3	Better balance and walking a little better, better range of motion in feet, standing on toes
7	Sep 11	2	2, 2	Better balance and walking a little better, better range of motion in feet, standing on toes; was able to drive car
8	Sep 12	2	1, 2	Continued improvements related to symptoms noted on previous day
9	Sep 13	2	2, 3	Continued improvements related to symptoms noted on previous day
10	Sep 14	3	1, 2, 3	Continued improvements related to symptoms noted on previous day
11	Sep 15	3	1, 2, 3	Continued improvements related to symptoms noted on previous day
12	Sep 16	2	1, 2, 3	Continued improvements related to symptoms noted on previous day
13	Sep 17	2	1, 2, 3	Continued improvements related to symptoms noted on previous day

Summary

Many patients experience iatrogenic effects following the administration of chemotherapy (URMC, 2008). Because the use of such drugs is common practice in cancer treatment, it is important to provide patients with methods to relieve their distress. There is limited research on the use of neurofeedback to treat physical health issues related to balance, walking gait, and neuropathy. However, this single case study offers promising evidence that these conditions might be addressed and improved with neurofeedback treatment. Further research in treating neuropathy should be conducted in order to assess the benefits and efficacy of neurofeedback for this condition.

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