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Attention, Executive Function, Behavior, and Electrocortical Function, Significantly Improved With 19-Channel *Z*-Score Neurofeedback in a Clinical Setting: A Pilot Study

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Abstract

Objective: Neurofeedback (NF) is gaining recognition as an evidence-based intervention grounded in learning theory, and 19-channel z-score NF (19ZNF) is a new NF model. This pilot study sought to evaluate the efficacy of 19ZNF in a clinical setting. **Method:** Outcome measures framed groups such that 19ZNF was evaluated, as it relates to the neuropsychological constructs of attention (n = 10), executive function (n = 12), behavior (n = 14), and electrocortical functioning (n = 21). One-tailed t tests compared pre–post difference scores. **Results:** For all pre–post comparisons, the direction of change was in the predicted direction, and differences were statistically significant (p = .000 to p = .008, effect sizes 1.29 to 3.42). **Conclusion:** Results suggest 19ZNF improved attention, executive function, behavior, and electrocortical function. This study provides beginning evidence of 19ZNF's efficacy, adds to what is known about 19ZNF, and offers an innovative approach for using quantitative electroencephalographic (QEEG) metrics as outcome measures. *(J. of Att. Dis. XXXX; XX(X) XX-XX)*

Keywords

neurofeedback, QEEG, z-score neurofeedback, 19-channel z-score neurofeedback, EEG biofeedback, 19ZNF

Introduction

Neurofeedback (NF) is an operant conditioning brainwave biofeedback technique, which is also referred to as electroencephalographic (EEG) biofeedback. This modality, dating back to the 1970s (Lubar & Shouse, 1976; Sterman & Friar, 1972), trains electrical signals of targeted frequencies and involves recording EEG data from scalp sensors with an amplifier, which is subsequently processed by computer software. The software provides visual and auditory feedback to the trainee, thereby providing a reward stimulus when the brain is functioning in the target range. This reward process generates learning such that the brain's functioning is conditioned in the intended manner.

In recent years, NF has seen increasing acceptance as a therapeutic intervention. Current literature includes reviews and meta-analyses, which establish a recognition of NF as effective for the specific condition of ADHD (Arns, de Ridder, Strehl, Breteler, & Coenen, 2009; Brandeis, 2011; Gevensleben, Rothenberger, Moll, & Heinrich, 2012; Lofthouse, Arnold, Hersch, Hurt, & DeBeus, 2012; Niv, 2013; Pigott, De Biase, Bodenhamer-Davis, & Davis, 2013). However, the type of NF covered in these reviews is primarily limited to the older NF model (theta/beta ratio) and/or slow cortical potential NF. Yet, of note are reports in the literature of a different NF model which is informed by quantitative EEG (QEEG) data. This QEEG-guided NF (QNF) is reported to be used for a much wider range of conditions, not only ADHD but also conditions involving executive dysfunction, behavior, and electrocortical dysfunction (such as cognitive dysfunction, various mood disorders, epilepsy, post-traumatic stress disorder, head injuries, autism disorders, migraines, behavior and learning disorders, schizophrenia, and mental retardation; Arns, Drinkenburg, & Kenemans, 2012; Breteler, Arns, Peters, Giepmans, & Verhoeven, 2010; Coben & Myers, 2010; Koberda, Hillier, Jones, Moses, & Koberda, 2012; Surmeli

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& Ertem, 2009, 2010, 2011; Surmeli, Ertem, Eralp, & Kos, 2012; Walker, 2009, 2010b, 2011, 2012).

Collectively, though, all the aforementioned models are limited in their use of only one or two electrodes and they also require many sessions to achieve good clinical outcomes. For the above-cited studies, the reported average number of sessions was 40.5. Moreover, Thatcher (2012, 2013) reports 40 to 80 sessions to be the accepted norm for the older style models, thus leading to a sizeable cost to access this treatment. Over the years, a more current model, a style of NF termed *z*-score NF (ZNF), was developed.

ZNF is different from the traditional NF models in that it incorporates into the NF session real-time QEEG *z*-score metrics, making it possible to combine operant conditioning with real-time assessment using a normative database (Collura, Thatcher, Smith, Lambos, & Stark, 2009; Thatcher, 2012). In 2006, a 4-channel ZNF (4ZNF) technique was introduced, which in 2009 was expanded to include all 19 sites of the International 10-20 System (of electrode placement) to allow for a 19-channel ZNF (19ZNF). To date, case study and clinical reports within the NF field indicate that this new 19ZNF approach is an improvement over traditional NF models (Koberda, Moses, Koberda, & Koberda, 2012b; Wigton, 2013) and shows promise to bring about positive significant clinical outcomes in fewer sessions (Thatcher, 2013; Wigton, 2013). Clinical reviews and conference reports (Koberda, Moses, Koberda, & Koberda, 2012a; Rutter, 2011; Wigton, 2009, 2010a, 2010b, 2013; Wigton & Krigbaum, 2012) suggest 19ZNF can result in positive clinical outcomes, as well as QEEG normalization, in as few as 5 to 15 sessions, thereby reducing treatment cost.

Currently, there are descriptive, clinical review articles *about* the 19ZNF model (Thatcher, 2013; Wigton, 2013), as well as case study reports (Hallman, 2012; Koberda et al., 2012b); however, rigorous scientific studies evaluating 19ZNF are scant. Thus, empirical studies to establish evidence-based efficacy of this new model are needed. NF efficacy has been discussed as having the desired effect in terms of improved clinical outcomes (La Vaque et al., 2002; Thatcher, 2013; Wigton, 2013). In this pilot study, there are two forms of clinical outcome measures. One form, clinical assessments, is designed to measure symptom severity and/or improvement of attention, executive function, and behavior. The assessment used to measure attention was the Integrated Visual and Auditory Continuous Performance Test (IVA; BrainTrain, Inc., Chesterfield, VA), to measure executive function was the Behavior Rating Inventory of Executive Functioning (BRIEF; Western Psychological Services, Incorporated, Torrance, CA), and to measure behavior was the Devereux Scale of Mental Disorders (DSMD; Pearson Education, Incorporated, San Antonio, TX). The other form of clinical outcome measure, QEEG *z* scores, provides a representative measure of electrocortical dysfunction and/or improvement. Hughes and John (1999) demonstrated EEG/QEEG measures to be sensitive to psychiatric disorders. These EEG/QEEG measures are founded on the premise that electrocortical dysfunctions correspond with clinical symptoms and mental disorders (Coben & Myers, 2010; Collura, 2010; Walker, 2010a), such that clinical symptoms can be linked to brain dysregulation (Thatcher, 2013). So, when NF results in symptom resolution and QEEG normalization (i.e., *z* scores moving toward $z = 0$), it yields improvement in electrocortical functioning (Arns et al., 2012; Walker, 2010a).

This research intended to investigate surface 19ZNF, through a retrospective evaluation of clinical outcomes, as measured by clinical assessments and QEEG *z* scores to address clinical efficacy. The research questions inquired 19ZNF improvement in the following: attention as measured by the IVA, executive function as measured by the BRIEF, behavior as measured by the DSMD, and electrocortical function as measured by QEEG *z* scores.

Method

Sample

The population for this research included those who participate in NF training (both adults and children) to address an array of symptoms, which adversely affects their daily functioning, most commonly in the areas of attention, executive function, and behavior. The sample from this population was a retrospective convenience sample, from reviewed closed cases, of clients from a private NF practice; none reported experiencing NF prior to coming to this practice. These clients met the inclusion criteria of being administered the clinical assessments and QEEGs before and after 19ZNF treatment. At this clinic, all clients sign an informed consent form before treatment is provided. They are informed that after their treatment is completed and their case closed, non-identifying data could be included in a limited data set, for quality assurance and/or future research purposes; they are all given the opportunity to opt out. University institutional review board (IRB) approval was obtained prior to collecting a limited data set, containing only de-identified data.

The clinical symptoms presented during the intake assessment corresponded with the *z*-score deviations of the QEEG findings, such that a treatment goal of overall QEEG normalization was clinically appropriate. A priori power analysis concluded the minimum sample size needed for 0.80 power was $n = 8$. As depicted in Figure 1, from the available 19ZNF cases, an initial group was formed for which pre–post QEEG assessments existed, and for which *either* the IVA, BRIEF, *or* DSMD pre–post assessment data were also available ($n = 21$). From this collection, three additional groups were formed. One group was created for

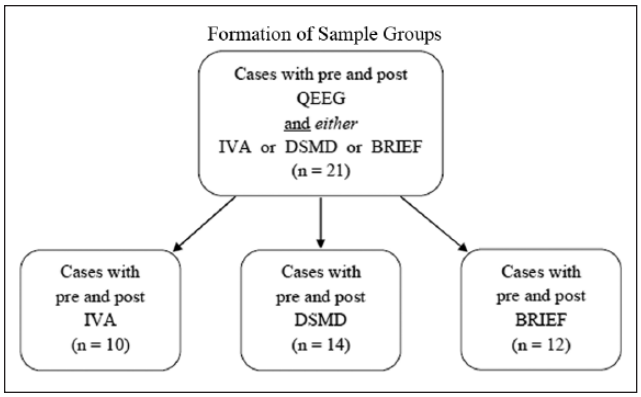

Figure 1. Illustration of how the sample groups were formed.
Note. The total number of participants in the sample is 21. However, out of those 21, some may have multiple assessments, and therefore, participants may be in more than one clinical assessment group. QEEG = quantitative EEG; IVA = Integrated Visual and Auditory Continuous Performance Test; DSMD = Devereux Scale of Mental Disorders; BRIEF = Behavior Rating Inventory of Executive Functioning.

the IVA data (n = 10), a second group for the DSMD data (n = 14), and a third group for the BRIEF data (n = 12). Each of the clinical assessments framed a sample group such that the efficacy of 19ZNF was evaluated.

As presented in Table 1, the descriptive makeup of the study sample is summarized for the four groups (QEEG, IVA, DSMD, and BRIEF). It is important to note that although the clinical assessment groups were diverse diagnostically, when viewed by clinical complaints, in terms of the neuropsychological constructs of attention, behavior, or executive function, the participants collectively formed well-defined groups, for which the assessment instruments are designed to measure.

The mean age for the QEEG group was 21.19 years (SD = 18.12), for the IVA group 26.80 years (SD = 19.84), for the DSMD group 10.86 years (SD = 2.91), and for the BRIEF group 20.25 years (SD = 19.97). More children were represented in the sample (QEEG = 15, IVA = 5, DSMD = 14, BRIEF = 10) than adults (QEEG = 6, IVA = 5, DSMD = 0, BRIEF = 2). It is reasonable to expect that having more children than adults did not adversely affect results, as each assessment instrument measured severity of symptoms that can adversely affect daily life of children and adults equally. Moreover, with respect to the effect of age on NF, the research of Arns et al. (2012), which included both adults and children (two thirds and one third, respectively), found no statistical difference in NF effects between adults and children. In addition, in Kaiser and Othmer's (2000) retrospective pretest–postest study of children and adults (726 and 363, respectively), which found that NF leads to significant clinical improvement in 85% of participants, no differences in NF effects were reported between children and adults. With regard to the dependent variables (attention, executive function, behavior, and electrocortical function), given that the outcome measures results are derived from computations based on normative data, from age-referenced databases, there is no reason to expect effects of age, between children and adults, on these variables.

Overall, the sample was made up of adults and children with diagnoses mostly related to ADHD: primarily ADHD-Inattentive (ADHD-I) and ADHD-Combined (ADHD-C) types comorbid with other conditions. The QEEG group included four ADHD-I and seven ADHD-C, three with ADHD-C comorbid with another disorder (ADHD-C/unspecified anxiety disorder, ADHD-C/autism spectrum disorder, ADHD-C/unspecified learning disorder), as well as one each comorbid unspecified anxiety/unspecified depressive disorder, autism spectrum disorder, unspecified bipolar disorder, reactive attachment disorder, comorbid obsessive-compulsive disorder/issues with executive function, and two with presenting issues of difficulty with executive functioning. The IVA group included three ADHD-I and four ADHD-C, two with ADHD-C comorbid with another disorder (ADHD-C/unspecified anxiety disorder, ADHD-C/unspecified learning disorder), and one with presenting issues of difficulty with executive functioning. The DSMD group included two ADHD-I, five ADHD-C, two with ADHD-C comorbid with another disorder (ADHD-C/autism spectrum disorder, ADHD-C/unspecified learning disorder), as well as one each comorbid unspecified anxiety/unspecified depressive disorder, autism spectrum disorder, unspecified bipolar disorder, reactive attachment disorder, and one with presenting issues of difficulty with executive functioning. The BRIEF group included two each with ADHD-I and ADHD-C, two with ADHD-C comorbid with another disorder (ADHD-C/autism spectrum disorder, ADHD-C/unspecified learning disorder), as well as one each with comorbid unspecified anxiety/unspecified depressive disorder, autism spectrum disorder, reactive attachment disorder, comorbid obsessive-compulsive disorder and issues with executive function, and two with presenting issues of difficulty with executive functioning.

The frequency of cases involving medication use in this study was 5 out of 21 for the QEEG group, 2 out of 10 in the IVA group, 3 out of 14 for the DSMD group, and 2 out of 12 for the BRIEF group. Other sample characteristics consistent across all groups were evenly divided with respect to gender, were primarily ethnically White, and were mostly medium socioeconomic status (SES).

Although the sample composition was heterogeneous regarding age, diagnosis, and medication usage, this sample was a fairly accurate representation of the overall population that has been seen in this clinic for close to 15 years. Therefore, whereas an argument could be made that a data set with a single diagnosis, only children or adults, and/or no medication usage may provide for a stronger study, in

Table 1. Descriptive Data for All Groups.

Category	QEEG group (*n* = 21)	IVA group (*n* = 10)	DSMD group (*n* = 14)	BRIEF group (*n* =12)
Age *M* (*SD*)	21.19 (18.12)	26.80 (19.84)	10.86 (2.91)	20.25 (19.97)
Children	15	5	14	10
Adults	6	5	0	2
Gender				
Male	10	5	7	6
Female	11	5	7	6
Ethnicity				
White	17	9	10	11
Asian	2	0	2	1
Latino	2	1	2	0
Socioeconomic status				
Low	5	3	3	2
Medium	14	5	9	9
High	2	2	2	1
Diagnosis or condition				
ADHD-Inattentive	4	3	2	2
ADHD-Combined	7	4	5	2
ADHD-C/anxiety	1	1	0	0
ADHD-C/ASD	1	0	1	1
ADHD-C/LD	1	1	1	1
Anxiety/depression	1	0	1	1
ASD	1	0	1	1
Bipolar	1	0	1	0
Executive function	2	1	1	2
OCD/executive function	1	0	0	1
RAD	1	0	1	1
Medication				
No	16	8	11	10
Yes	2	1	1	1
Yes to off	2	1	1	1
Yes to reduced	1	0	1	0
No. of sessions pre-to-post *M* (*SD*)	10.90 (3.88)	9.70 (3.92)	11.43 (4.13)	11.83 (2.69)
No. of weeks for treatment *M* (*SD*)	11.76 (5.19)	9.40 (4.40)	12.57 (5.60)	13.50 (3.97)
No. of weeks pre-to-post assessment *M* (*SD*)	15.10 (10.03)	13.20 (11.11)	15.36 (8.63)	16.17 (8.44)

Note. QEEG = quantitative EEG; IVA = Integrated Visual and Auditory Continuous Performance Test; DSMD = Devereux Scale of Mental Disorders; BRIEF = Behavior Rating Inventory of Executive Functioning; ASD = autism spectrum disorder; LD = learning disorder; OCD = obsessive-compulsive disorder; RAD = reactive attachment disorder.

reality, the data in this research made the results more generalizable to the population of those who actually seek NF services. Thus, this study provides an opportunity to evaluate the 19ZNF intervention using realistic information typically found in a clinical setting.

Outcome Measures

Clinical assessments. The focus of the IVA group was attention. The IVA is a 13-min computerized performance test, with 500 responding or inhibiting trials, normed for ages 6 years to adult, designed to assess both auditory and visual attention and impulse control (Sanford & Turner, 2009). As a performance test, the IVA is completed directly by the participant. Only the scales specific to attention, the Auditory Attention, Visual Attention, and Full Scale, were included for analysis in this study. The test results are reported in the form of quotient scores such that a score of ≤85 is indicative of clinical significance.

The focus of the BRIEF group was executive function. The BRIEF is a rating scale, with 86 items, designed to sample observations of children's (aged 5-18 years) executive function skills in everyday natural settings, with forms suitable for completion by parents and teachers (Donders, 2002). For this study, only the parent form was available. This instrument is intended to assess behavioral, emotional, and metacognitive skills, which broadly encompass executive skills, rather than measure behavior problems or psychopathology (Donders, 2002). The BRIEF-A is the adult version (ages 18-90), self-report form, with 75 items, which is designed to assess the views of one's own executive function skills (self-regulation) in their everyday environment (Gioia, Isquith, Guy, & Kenworthy, 2000). For this study, only the self-report form was available. Only the composite scales of Behavioral Regulation Index (BRI), Metacognition Index (MI), and Global Executive Composite (GEC) were included for analysis in this study. Both assessments take approximately 15 min to complete, and scores are expressed in terms of *T* scores, with scores ≥65 indicating clinical significance (Gioia et al., 2000; Roth, Isquith, & Gioia, 2005).

The focus of the DSMD group was behavior. The DSMD is a behavior rating scale designed to assess behavior problems and psychopathology in children and adolescents; the child form (ages 5-12) and adolescent forms (ages 13-18) have 110 items that describe problem behaviors, with a 65% overlap between the two forms (Cooper, 2001). The rater can be either a parent or a teacher, with separate norms for each; in this research, only parent ratings were used. Only the scales specific to behavior, the Externalizing, Internalizing, and Total scales were included for analysis in this study. The instrument scores are expressed in *T* scores, with scores ≥60 indicating clinical significance, and can be completed in about 15 min.

QEEG z scores and EEG acquisition. The focus of the QEEG group was electrocortical function. The QEEG *z* scores are a representational measure of electrocortical function, such that *z* scores closer to the mean represent improved functioning. Therefore, QEEG normalization is defined as the targeted *z* scores moving toward $z = 0$. The *z*-score data were

calculated for the QEEG metrics of Absolute Power, Relative Power, and Coherence; the same procedure was followed for each metric. Building on the sites-of-interest (SoI) by Krigbaum and Wigton (2015), rather than separating the positive and negative *z* scores, the *z* scores were, instead, transformed to the absolute value. The transformed pre-*z*-scores ≥1.0 were highlighted as being the targeted (by site and frequency) *z* scores. Those targeted *z* scores were averaged to create a single value, representing an overall measure of distance from the mean for that metric, for that case. Next, the same targeted *z* scores for the corresponding post-values (i.e., same site and frequency) were identified and averaged. This allowed the pre- and post-averaged targeted *z*-score values to be compared, as a measure of change, such that a lower post-value (compared with the pre-value) would be closer to the mean (i.e., overall normalization).

The QEEG data was acquired and processed with the Neuroguide software (Applied Neuroscience Inc., St. Petersburg, FL), which allows the EEG data to be compared with the Lifespan Normative database. This database has been normed, for both eyes open and eyes closed conditions, with 625 individuals from ages of 2 months to 82 years, with the included participants being screened for normalcy (i.e., normal intelligence, lack of pathology, or mental health disorders) through history, interviews, neuropsychological testing, and other evaluations (Thatcher, Walker, Biver, North, & Curtin, 2003). The amplifier used for the EEG acquisition was the Brainmaster-Discovery 24E (Brainmaster Technologies, Inc., Bedford, OH; Discovery version 1.4), with an EEG bandwidth of 0.43-80 Hz, A/D conversion of 24 bits (resolution of 0.01 μV EEG, 0.4 μV DC), a sampling rate of 1024 samples per second (data rate to the computer of 256 samples per second), and input impedance of 1000 GΩ.

EEG data were acquired and processed as has been described by Krigbaum and Wigton (2015), using accepted standards of QEEG acquisition methods, thus ensuring quality recordings. An electrode cap (Electro-Cap Inc.; Eaton, OH) was used to place the 19 electrodes according to the International 10-20 System referenced to linked ears, using tin electrodes and Electro-Cap brand electro-conductive gel. Electrode impedances were adjusted to be below 10 kΩ for all electrodes and balanced. The digital format of the EEG recording was with a high-pass filter of 0.5 Hz and a low-pass filter of 50 Hz, as acquired with the Neuroguide EEG acquisition software. The pre- and post-EEG recordings were acquired with eyes open in a waking-relaxed state, sitting in an upright relaxed position. The instructions given were to remain still, inhibit muscle activity from forehead, neck, and jaws, as well as eye movements and blinks. Screening of EEG was conducted carefully to exclude technical and biological artifacts. The *EEG Selection* method (Thatcher, 2012), as implemented in Version 2.7.3 of the software, was used to eliminate artifacts prior to submitting the EEG to a fast Fourier transformation (FFT) procedure. This method consisted of selecting 2 s of artifact-free data that the software then uses as a template to automatically select the remaining artifact-free EEG data. The remaining edited EEG consisted of an average of 1 min of data (thirty 2-s epochs), thus ensuring a representative sample of data verified by the split-half and test–retest values being ≥.90, in keeping with EEG reliability studies found in the literature (i.e., Gasser, Bacher, & Steinberg, 1985; Salinsky, Oken, & Morehead, 1991). The digitally filtered frequency bands, for surface potential metrics of Absolute Power, Relative Power, and Coherence, were as follows: delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta1 (12-15 Hz), beta2 (15-18 Hz), beta3 (18-25 Hz), and high beta (25-30 Hz).

NF Treatment

All treatments were provided by the first author who is a licensed professional counselor and board certified NF therapist. While the 19ZNF protocol developed for each case is individually tailored to the clinical and QEEG findings, and adapted at each session to correspond with the baseline QEEG data of that day, the same treatment goal always applies, that of overall QEEG normalization. The underlying 19ZNF protocol of overall QEEG normalization is consistent for all cases. The hardware platform was the Brainmaster Discovery 24E amplifier, and the software platform was either the Brainmaster Discovery PZOK or Neuroguide NF-1 19ZNF software. The 19ZNF sessions incorporated the Brainmaster Flashgame visual NF displays (i.e., simple non-movie animations) and discrete auditory reward tones; the reward percentages for all protocols and sessions were 30% to 50% (Brainmaster platform protocols) or 20 to 30 rewards-per-minute (Neuroguide platform protocols).

The session descriptive parameters are presented in Table 1. The mean number of sessions from pre-assessment to post-assessment for the QEEG group was 10.90 (*SD* = 3.88), for the IVA group 9.70 (*SD* = 3.92), for the DSMD group 11.43 (*SD* = 4.13), and for the BRIEF group 11.83 (*SD* = 2.69). The targeted session frequency for all groups was once per week. The mean number of weeks for treatment for the QEEG group was 11.76 (*SD* = 5.19), for the IVA group 9.40 (*SD* = 4.40), for the DSMD group 12.57 (*SD* = 5.60), and for the BRIEF group 13.50 (*SD* = 3.97). The mean number of weeks from pre-assessment to post-assessment for the QEEG group was 15.10 (*SD* = 10.03), for the IVA group 13.20 (*SD* = 11.11), for the DSMD group 15.36 (*SD* = 8.63), and for the BRIEF group 16.17 (*SD* = 8.44).

Statistical Analysis

The statistical analysis was conducted with the SPSS v21 statistical package. Prior to analysis, the data was reviewed

Table 2. Summary of Results—All Groups.

Group scales	Pre-scores *M* (*SD*)	Post-scores *M* (*SD*)	*t*(*df*)	*p*	Hedges' *d*
IVA					
Audio Attention	86.50 (14.11)	106.20 (10.76)	−4.29 (9)	.001	1.84
Visual Attention	83.60 (19.37)	103.70 (13.21)	−3.00 (9)	.008	1.29
Full Scale Attention	83.40 (18.23)	105.60 (12.25)	−3.78 (9)	.002	1.62
DSMD					
Externalizing	68.21 (15.49)	57.71 (12.87)	4.97 (13)	.000	1.83
Internalizing	66.21 (9.82)	57.29 (9.85)	6.43 (13)	.000	2.36
Total	65.00 (10.58)	55.64 (10.76)	9.36 (13)	.000	3.42
BRIEF					
BRI	71.00 (11.40)	60.17 (10.27)	4.37 (11)	.001	1.72
MI	76.08 (8.24)	65.67 (10.36)	4.39 (11)	.001	1.73
GEC	75.75 (9.33)	64.50 (9.91)	4.66 (11)	.000	1.84
QEEG z scores					
Absolute Power	1.46 (0.28)	1.03 (0.37)	7.73 (20)	.000	2.29
Relative Power	1.51 (0.22)	1.13 (0.35)	5.22 (20)	.000	1.76
Coherence	1.46 (0.14)	0.96 (0.32)	6.55 (20)	.000	1.88

Note. IVA = Integrated Visual and Auditory Continuous Performance Test; DSMD = Devereux Scale of Mental Disorders; BRIEF = Behavior Rating Inventory of Executive Functioning; BRI = Behavioral Regulation Index; MI = Metacognition Index; GEC = Global Executive Composite; QEEG = quantitative EEG.

and there were no outliers or missing data found. The Shapiro–Wilk test was used to check the difference scores for normality. The Shapiro–Wilk computations for all scales, in all groups, resulted in $p > .05$ (ranging from $p = .084$ to $p = .980$), thus ensuring that the difference scores met the normality assumption. For all of the research questions, the group mean direction of change was first determined. Then, one-tailed paired *t* tests were performed to compare the means of the pre- and post-scores, for the selected scales and *z* scores, for each outcome measure. Finally, the Hedges' *d* effect size (H*d*) was calculated.

Results

For all pre–post comparisons, the change in the scores was in the predicted direction. Moreover, for all the outcome measures, the averaged scores were at or beyond the clinically significant threshold before 19ZNF and changed to no longer being so after 19ZNF. Finally, for all research questions, the null hypothesis was rejected, in favor of the conclusion that 19ZNF improved attention, executive function, behavior, and electrocortical function. Table 2 provides a cumulative summary of the results of the findings for all groups, and Figure 2 provides a graphical representation of the pre- and post-scale scores for each of the groups.

For the IVA group, the scales of Auditory Attention, Visual Attention, and Full Scale were evaluated, with the threshold for clinical significance being ≤85. The mean of the Auditory Attention scale pre-scores was 86.50 (*SD* = 14.11, 95% CI = [76.40, 96.60]), and the mean of the post-scores was 106.20 (*SD* = 10.76, 95% CI = [98.50, 113.90]). The mean of the Visual Attention scale pre-scores was 83.60 (*SD* = 19.37, 95% CI = [69.74, 97.46]), and the mean of the post-scores was 103.70 (*SD* = 13.21, 95% CI = [94.25, 113.15]). The mean of the Full Scale pre-scores was 83.40 (*SD* = 18.23, 95% CI = [70.36, 96.44]), and the mean of the post-scores was 105.60 (*SD* = 12.25, 95% CI = [96.84, 114.36]). The one-tailed *t*-test results showed the pre- and post-scores differed significantly, with the Auditory Attention scale $t(9) = -4.29$, $p = .001$, H$d = 1.84$; the Visual Attention scale $t(9) = -3.00$, $p = .008$, H$d = 1.29$; and the Full Scale $t(9) = -3.78$, $p = .002$, H$d = 1.62$.

For the DSMD group, the scales of Externalizing, Internalizing, and Total were evaluated, with the threshold for clinical significance being ≥60. The mean of the Externalizing scale pre-scores was 68.21 (*SD* = 15.49, 95% CI = [59.27, 77.16]), and the mean of the post-scores was 57.71 (*SD* = 12.87, 95% CI = [50.28, 65.14]). The mean of the Internalizing scale pre-scores was 66.21 (*SD* = 9.82, 95% CI = [60.55, 71.88]), and the mean of the post-scores was 57.29 (*SD* = 9.85, 95% CI = [51.60, 62.97]). The mean of the Total scale pre-scores was 65.00 (*SD* = 10.58, 95% CI = [58.89, 71.11]), and the mean of the post-scores was 55.64 (*SD* = 10.76, 95% CI = [49.43, 61.86]). The one-tailed *t*-test results showed the pre- and post-scores differed significantly, with the Externalizing scale $t(13) = 4.97$, $p = .000$, H$d = 1.83$; the Internalizing scale $t(13) = 6.43$, $p = .000$, H$d = 2.36$; and the Total scale $t(13) = 9.36$, $p = .000$, H$d = 3.42$.

For the BRIEF group, the scales of BRI, MI, and GEC were evaluated; with the threshold for clinical significance being ≥65. The mean of the BRI scale pre-scores was 71.00 (*SD* = 11.40, 95% CI = [63.77, 78.23]), and the mean of the

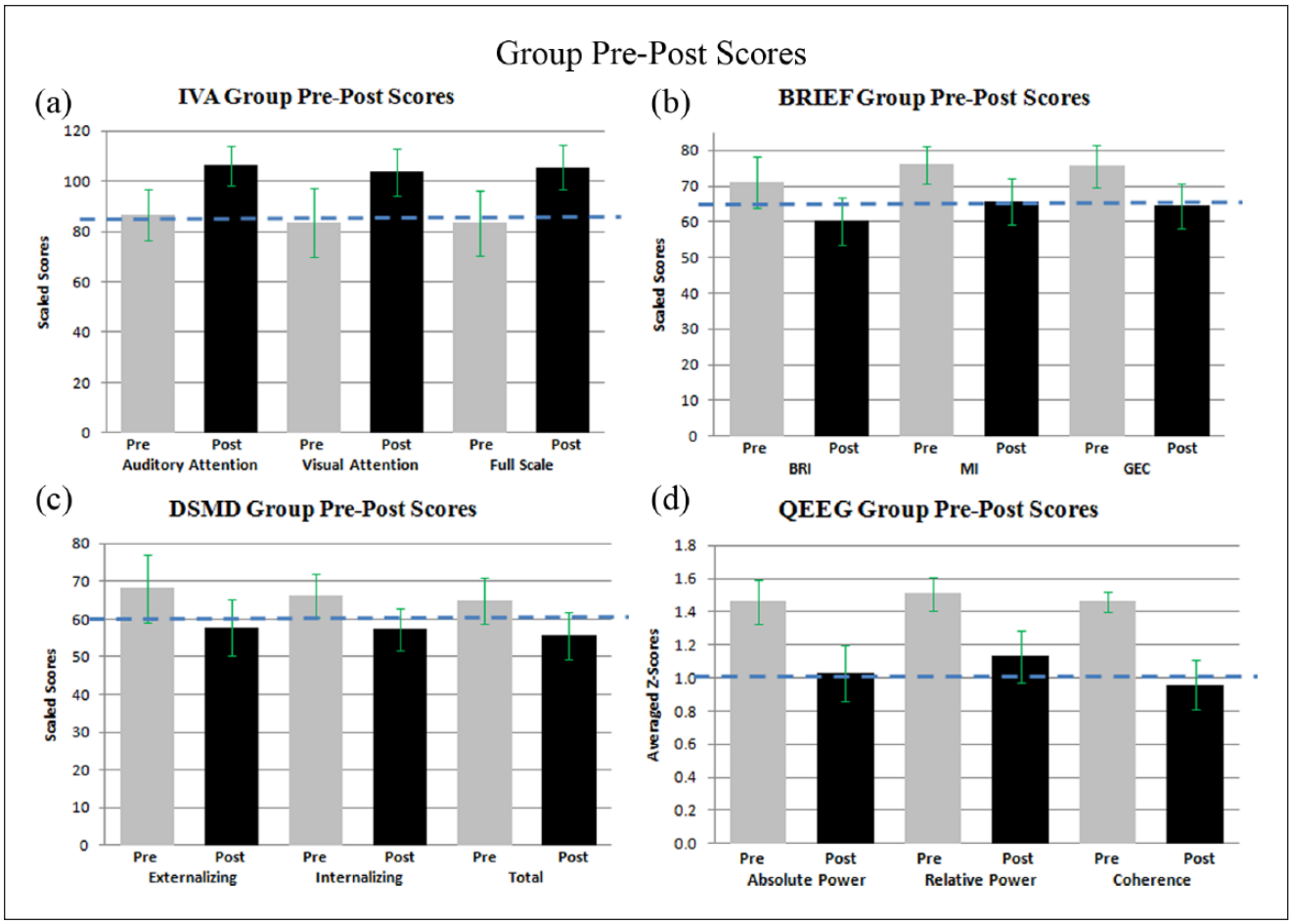

Figure 2. (a) Mean IVA group standard scores before and after 19ZNF sessions. The dotted line indicates threshold for clinical significance; values at or below the line suggest clinically relevant symptoms. Post-values above the line suggest improvements in attention. All post-scores are statistically significant at $p \leq .008$.
(b) Mean BRIEF group standard scores before and after 19ZNF sessions. The dotted line indicates threshold for clinical significance; values at or above the line suggest clinically relevant symptoms. Post-values below the line suggest improvements in executive function. All post-scores are statistically significant at $p \leq .001$.
(c) Mean DSMD group standard scores before and after 19ZNF sessions. The dotted line indicates threshold for clinical significance; values at or above the line suggest clinically relevant symptoms. Post-values below the line suggest improvements in behavior. All post-scores are statistically significant at $p = .000$.
(d) Mean QEEG group targeted *z* scores before and after 19ZNF sessions. The dotted line indicates threshold for inclusion as targeted *z* scores; values above the line suggest electrocortical dysfunction. Post-values at or below the line suggest improvements in electrocortical function. All post-scores are statistically significant at $p = .000$.
Note. IVA = Integrated Visual and Auditory Continuous Performance Test; 19ZNF = 19-channel *z*-score neurofeedback; BRIEF = Behavior Rating Inventory of Executive Functioning; DSMD = Devereux Scale of Mental Disorders; QEEG = quantitative EEG.

post-scores was 60.17 (*SD* = 10.27, 95% CI = [53.64, 66.69]). The mean of the MI scale pre-scores was 76.08 (*SD* = 8.24, 95% CI = [70.85, 81.32]), and the mean of the post-scores was 65.67 (*SD* = 10.36, 95% CI = [59.08, 72.25]). The mean of the GEC scale pre-scores was 75.75 (*SD* = 9.33, 95% CI = [69.82, 81.68]), and the mean of the post-scores was 64.50 (*SD* = 9.91, 95% CI = [58.20, 70.80]). The one-tailed *t*-test results showed the pre- and post-scores differed significantly, with the BRI scale $t(11) = 4.37$, $p = .001$, H*d* = 1.72; the MI scale $t(11) = 4.39$, $p = .001$, H*d* = 1.73; and the GEC scale $t(11) = 4.66$, $p = .000$, H*d* = 1.84.

For the QEEG group, the metrics of Absolute Power, Relative Power, and Coherence were evaluated, with the targeted transformed *z*-score threshold value being $z \geq 1.00$. The mean of the Absolute Power pre-*z*-scores was 1.46 (*SD* = 0.28, 95% CI = [1.33, 1.59]), and the mean of the post-scores was 1.03 (*SD* = 0.37, 95% CI = [0.87, 1.20]). The mean of the Relative Power pre-*z*-scores was 1.51 (*SD* = 0.22, 95% CI = [1.41, 1.61]), and the mean of the post-scores was 1.13 (*SD* = 0.35, 95% CI = [0.97, 1.29]). The mean of the Coherence pre-*z*-scores was 1.46 (*SD* = 0.14, 95% CI = [1.40, 1.53]), and the mean of the post-scores was 0.96 (*SD* =

0.32, 95% CI = [0.82, 1.11]). The one-tailed *t*-test results showed that the pre- and post-scores differed significantly, with the Absolute Power $t(20) = 7.73$, $p = .000$, H$d = 2.29$; the Relative Power $t(20) = 5.22$, $p = .000$, H$d = 1.76$; and the Coherence $t(20) = 6.55$, $p = .000$, H$d = 1.88$.

Overall, all clinical assessment groups collectively exhibited symptoms of attention dysfunction, compromised executive function, behavioral issues, and electrocortical dysregulation, as demonstrated by the pre-test measures. After 19ZNF, the participants' scores on the post-test assessments, for all groups, significantly improved. Thus, the 19ZNF resulted in positive clinical outcomes of improved attention, executive function, behavior, and electrocortical function. More so, the improvements were attained within an approximate average of 10 sessions of 19ZNF, ranging from a mean of 9.70 to 11.83 sessions across the four groups.

Discussion

Operant conditioning is the theoretical foundation of NF, with demonstrated efficacy in improving brain functioning and clinical symptoms, through the resulting electrocortical changes. However, whether this also holds true for the new 19ZNF model was an outstanding question. The aim of this pilot study was to provide the beginnings of an evidence-based foundation for the efficacy of 19ZNF. The focus was to evaluate if 19ZNF would result in improved clinical symptoms and electrocortical function as measured by the identified outcome measures. In general, the findings of this research are that attention, executive function, behavior, and electrocortical function all improved after approximately ten 19ZNF sessions. This study also supports the reports of Krigbaum and Wigton (2015), Thatcher (2013), and Wigton (2013) that 19ZNF results in improvement in clinical symptoms in fewer sessions than the 40+ sessions typical in traditional NF. Also notable is that the frequency of the sessions was an average of once per week, rather than the 2 to 3 times per week as is typical of traditional NF or QNF.

The greater specificity that QEEG-based methods allowed in treatment also creates research methodological challenges due to the need to account for both positive and negative *z* scores. This study's method of transforming the *z* scores to the absolute value, then tracking pre-to-post changes of the targeted *z* scores, presents a methodology for measuring overall normalization of the QEEG. More so, taking into account the effect size, Arns et al. (2009; Arns et al., 2012) have discussed, for traditional NF models, H*d* effect sizes were 0.7 and 1.0 for hyperactive and attention symptoms, respectively; yet for the QNF models, H*d* effect sizes were 1.2 and 1.8 (hyperactive and attention symptoms, respectively). In this research, H*d* effect sizes ranged from 1.29 to 3.42, with an average of 1.97. Therefore, the effect sizes for this research are similar, or greater, than what has been reported for QNF and traditional NF models. Moreover, if NF efficacy is defined in terms of large effect sizes when comparing pre–post outcome measure data (Arns et al., 2012), then the effect sizes of this pilot study support 19ZNF as being effective.

QEEG normalization is a theoretical construct, which has grown in popularity with the advent of the QNF model, as has the use of individually tailored QEEG-based protocols to bring about that normalization. In addition, clinical reports have suggested 19ZNF may exhibit better performance than traditional NF. These findings support 19ZNF as a NF modality that can bring about both QEEG normalization and symptom improvement efficiently, on average of approximately 10 sessions, at a target frequency of once per week. Therefore, in the context of this study, with the 19ZNF intervention at a frequency of only once per week (rather than the 2 to 3 times per week as other models), the outcome supports the efficacy of 19ZNF in improving attention, executive function, behavior, and electrocortical function.

This pilot study provides NF clients and clinicians with information regarding the efficacy of 19ZNF in improving attention, executive function, behavior, and electrocortical function. If 19ZNF is an efficacious evidence-based intervention, requiring fewer sessions than traditional NF or QNF, clients will benefit through the associated cost savings. These aspects, taken together, may potentially serve to reduce resistance of third-party payers to include NF as covered services.

Limitations

A general limitation of designs that incorporate a pre-test–post-test framework is primarily related to the passage of time between administering the pre- and post-assessments (Kerlinger & Lee, 2000). Factors such as history (concurrent events external to the study scope) and maturation (internal growth factors occurring regardless of interventions) cannot be controlled for. Therefore, it is not possible to know whether they have affected the dependent variable measures (Hunter & Schmidt, 2004). Yet, when the time between testing points is short, the impact of extraneous variation is lessened (Kerlinger & Lee, 2000; Reichardt, 2009). In this study, the time between the pre- and post-assessment was relatively short, measured in terms of weeks. Therefore, the impact of time-related confounds is considered to be minimal. Also, identified as a potential validity threat is the phenomenon of a regression to the mean, where high or low scores are, by chance, found to be closer to the mean when retested. However, there is an inverse relationship between the degree of statistical regression and an instrument's reliability (Kirk, 2009), such that instruments with higher reliability have less variability in the measurement error. Given the reliability of the

instruments in this study are relatively high, the estimate of the error of measurement is comparatively low. Moreover, in studies of psychological factors, where the intent is intervention evaluation, the behavior targeted by the treatment (i.e., the dependent variable) is typically quite difficult to change without some intervention (Hunter & Schmidt, 2004). Thus, potential validity threats related to regression effects are minimal.

Further limitations of this study include aspects inherent to retrospective studies using data from clinical settings, that being a finite data set, which can result in diagnostically diverse samples with heterogeneous demographics, as well as small sample sizes. However, when participants are viewed by clinical complaints, then collectively, well-defined groups can be formed, for which the instruments were designed to measure. Moreover, while the sample group sizes were small, the a priori power analysis demonstrated sufficient power for valid statistical analysis, and all statistical comparisons resulted in large effect sizes. This study also does not make a comparison with a traditional NF group or a randomized control group. Nevertheless, given the data for this research comes from a real-world clinical setting, the findings of this study can still contribute to advancing the empirical knowledge of 19ZNF.

Recommendations for Future Research

A single pilot study is insufficient to fully validate the efficacy of any treatment intervention. Thus, replication of this research would add to the empirical integrity of the results; however, doing so with larger sample sizes would, of course, be necessary. Next, follow-up studies are a needed area of focus. Although 19ZNF may be effective in the short-term, the question of whether the benefits hold over time is still outstanding. With 19ZNF being new among other approaches, ones backed by more research, direct comparisons to the traditional or QNF models are needed, particularly with randomized assignments. Additional suggestions for randomized control group research are for comparisons to waitlist groups. However, randomized controlled methods are less feasible in clinical settings, and as such, these studies will likely require university and/or grant-supported research settings (more conducive to true experimental designs) to complete. Other comparison research should also explore comparisons of 19ZNF using surface montages (as with this study) to 19ZNF using inverse-solution montages (e.g., low resolution electromagnetic tomography [LORETA]).

Few NF studies use QEEG metrics as a direct outcome measure, and even fewer do so in analyzing group means data. Therefore, an additional notable significance of this study is the novel development of a measure of overall QEEG normalization, by tracking the pre–post values of the targeted transformed *z* scores. Here too, though, replication and further validation are needed. Also recommended is an investigation of whether $z \pm 1.00$ is an optimal threshold value to determine targeted *z* scores.

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