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The Impact of Neurofeedback Training on Children With Developmental Trauma: A Randomized Controlled Study

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Objective: Developmental trauma or chronic early childhood exposure to abuse and neglect by caregivers has been shown to have a long-lasting pervasive impact on mental and neural development, including problems with attention, impulse control, self-regulation, and executive functioning. Its long-term effects are arguably the costliest public health challenge in the United States. Children with developmental trauma rarely have a satisfactory response to currently available evidence-based psychotherapeutic and pharmacological treatments. Neurofeedback training (NFT) is a clinical application of brain computer interface technology, aiming to alter electrical brain activity associated with various mental dysfunctions. NFT has shown promise to improve posttraumatic stress disorder (PTSD) symptoms. ***Method:*** This randomized controlled study examined the effects of NFT on 37 children, aged 6–13 years with developmental trauma. Participants were randomly divided into active NFT ($n = 20$) or treatment-as-usual control ($n = 17$). Both groups underwent 4 assessments during equivalent timelines. The active group received 24 NFT sessions twice a week. ***Results:*** This pilot study demonstrated that 24 sessions of NFT significantly decreased PTSD symptoms, internalizing, externalizing, other behavioral and emotional symptoms, and significantly improved the executive functioning of children aged 6–13 years with severe histories of abuse and neglect who had not significantly benefited from any previous therapy. ***Conclusions:*** NFT offers the possibility to improve learning, enhance self-efficacy, and develop better social relationships in this hitherto largely treatment-resistant population.

Clinical Impact Statement

Abuse and neglect of children by caregivers often have long-lasting and pervasive effects on mental and neural development, including problems with attention, impulse control, self-regulation, and executive functioning. Impairment of affect regulation is thought to be the largest obstacle to effective intervention. In this pilot study of neurofeedback for polysymptomatic children with such histories, we found a significant improvement on affect regulation and executive functioning after 24 sessions of neurofeedback treatment. This offers the possibility of being able to improve learning, enhance self-efficacy, and develop better social relationships in this hitherto largely treatment resistant population.

Keywords: neurofeedback, children, developmental trauma, posttraumatic stress disorder (PTSD)

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Chronic childhood exposure to violence, abuse, and/or neglect, recently formulated as developmental trauma (D'Andrea, Ford, Stolbach, Spinazzola, & van der Kolk, 2012; van der Kolk, Roth, Pelcovitz, Sunday, & Spinazzola, 2005), is arguably one of the long-term costliest public health challenges in the United States (Henry, Fulco, & Merrick, 2018). In federal Fiscal Year 2016, 3.5 million children in the United States were referred for investigations for potential maltreatment, and approximately 676,000 were substantiated as victims of abuse and neglect by child protective service systems (Zeanah & Humphreys, 2018). The majority of substantiated cases are maintained within their families, but approximately a quarter million new children enter into foster care each year, and 500,000 are in foster care at any given time in the United State (U.S. Department of Health and Human Services, 2017). The vast majority of these children experienced multiple types of maltreatment (Vachon, Krueger, Rogosch, & Cicchetti, 2015).

Chronic exposure to trauma early in the life cycle can have a pervasive impact on mental and neural development. Myriad research reports document a strong association between exposure to childhood victimization and far-ranging psychopathology (D'Andrea et al., 2012), accounting for an estimated 45% of the population-attributable risk for childhood-onset psychiatric disorders, including depression, anxiety, suicide attempts, psychosis, substance use disorders, self-regulatory disorders, and personality disorders (Green et al., 2010; Lippard & Nemeroff, 2020). Moreover, alterations in brain structure and function, as well as diminished cognitive functioning, have been well documented (Heim, Entringer, & Buss, 2019; Teicher & Samson, 2016). These children generally have a poor response to treatment (Nanni, Uher, & Danese, 2012).

Clinical problems tend to manifest as enduring difficulties regulating biological homeostasis and behavioral control, including problems with concentration, anger, panic, depression, food intake, drugs, sleep, interpersonal relationships, and academic performance (Holtmann et al., 2011; Spinazzola, van der Kolk, & Ford, 2018; van der Kolk, Ford, & Spinazzola, 2019; Zeanah et al., 2018). The number and complexity of symptoms and diagnoses in childhood increases proportionally to the extent of the trauma exposure (Ford, Elhai, Connor, & Frueh, 2010; Gustafsson, Nilsson, & Svedin, 2009; Spinazzola et al., 2018). These issues transcend and include many *Diagnostic and Statistical Manual of Mental Disorders* (DSM) diagnostic categories. Most children receive multiple internalizing and externalizing diagnoses (Cook et al., 2005; Ford, Connor, & Hawke, 2009). Surveys within the National Child Traumatic Stress Network have shown that children exposed to chronic trauma, abuse, and/or neglect are diagnosed with an average of three to eight different comorbid disorders (Ford et al., 2013). Although there is considerable support for the effectiveness of psychosocial treatments for relatively uncomplicated posttraumatic stress disorder (PTSD) in children (i.e., trauma that originates outside children's caregiving system) (Bartlett et al., 2017; Morina, Koerssen, & Pollet, 2016), meta-analytic reviews show that the majority of patients' PTSD symptoms are merely reduced but not eliminated (Berzenski, 2019; Lavi, Katz, Ozer, & Gross, 2019).

Children who receive multiple diagnoses as a result of early abuse and/or neglect within their caregiving system often are refractory to evidence-based treatment regimens and tend to receive costly and fragmented treatment regimens (Comer, Olfson, & Mojtabai, 2010; Grella & Joshi, 2003; Saldana, Chamberlain, Bradford, Campbell, & Landsverk, 2014; Sege et al., 2017). The main clinical issue that interferes with successful implementation of traditional evidence-based psychotherapeutic treatments is lack of affect regulation (Erwin et al., 2018; Heleniak, Jenness, Stoep, McCauley, & McLaughlin, 2016; Stover & Keeshin, 2018). There is little evidence that pharmacological interventions predictably improve affect regulation (Morina et al., 2016), which supports the urgent need to discover effective interventions to improve affect dysregulation.

Neurofeedback Training

Brain/computer interaction (BCI) devices are designed to alter neural signals and thereby mental and physical activity. BCIs can modify electroencephalographic (EEG) signals and associated mental functions, which makes them strong candidates to emerge as a new generation of psychiatric interventions (Edlinger, Rizzo, & Guger, 2011). Utilizing functional magnetic resonance imaging (fMRI) or EEG as basic information, BCIs can provide visual and/or auditory feedback about brain activity and thereby change neural activity. Whereas most BCI research has focused on helping physically disabled users communicate commands, in recent years the capacity of neurofeedback to alter EEG activity and associated mental functioning has started to be investigated (Ros et al., 2013), particularly in traumatized individuals (Kluetsch et al., 2014; Nicholson et al., 2016). EEG neurofeedback training (NFT) represents one of the earliest applications of BCIs, and even though it has been in use for about 3 decades with well-documented effects in more than 2,000 peer-reviewed scientific publications, serious questions remain about its clinical utility and the validity and scientific rigor of extant research (Hurt, Arnold, & Lofthouse, 2014).

This study explored the potential of NFT to improve PTSD symptomatology and various dimensions of affect regulation in multisymptomatic children with histories of chronic interpersonal trauma. In NFT, neural activity is recorded from scalp electrodes and provides feedback in real time to subjects in a readily understood, visual, and audio format (simple computer games). NFT is purported to change behavior by changing neuronal connectivity patterns in the central nervous system via operant conditioning. NFT is hypothesized to help individuals acquire self-regulation skills by stabilizing EEG activity and thereby improving focus and attention.

NFT has been shown to be capable of reshaping neural activity, as measured by EEG frequency components and fMRI (Beauregard & Lévesque, 2006; Kluetsch et al., 2014; Lawrence et al., 2014). NFT-induced EEG changes have been correlated with changes in functional outcomes, including corticomotor excitability, memory, cognition, sleep, and mood as well as increase in affect regulation and executive function, sustained attention, and working memory (Ros, Munneke, Parkinson, & Gruzelier, 2014; Zoefel, Huster, & Herrmann, 2011).

Clinical NFT has focused mainly on treating attention deficit/hyperactivity disorder (Van Doren et al., 2019). Two recent studies on the impact of NFT on adults with chronic PTSD showed that NFT has the potential of significantly improving PTSD symptomatology and executive functioning (Gapen et al., 2016; van der

Kolk et al., 2016). By the end of the second study, only 27.3% of the NFT group continued to meet PTSD diagnosis on the Clinician Administered PTSD Scale, compared with 68.2% in the control group.

The study of the efficacy of NFT for children with severe abuse and neglect is still in its infancy. An uncontrolled pilot study of quantitative EEG-guided NFT of 30–40 NFT sessions ($M = 38$) over the course of 2–8 months in 20 children aged 6–13 years with histories of abuse and neglect showed significant improvement in attention and behavior symptoms as measured by test of variables of attention and Child Behavior Checklist (CBCL) externalizing, internalizing, social, aggressive behavior, thought, delinquent behavior, anxiety/depression, and attention problems (Huang-Storms, Bodenhamer-Davis, Davis, & Dunn, 2006).

Method

Participants

The study included 37 children who had experienced multiple interpersonal traumatic events (see Figure 1), such as chronic neglect (33 children), impaired caregiver (33 children), separation from primary caregiver (35 children), physical abuse, and domestic violence, with an average of seven different types of traumas per participant. The demographics of the children are shown in Table 1. Children ranged in age from 6 to 13 years (mean 9.6 years; 24 males and 13 females). Racial and ethnicity was majority White ($n = 21$) and non-Hispanic ($n = 31$). Age and race did not differ significantly between the treatment and control/wait list (WL) control group. Nearly all the participants ($n = 35$ of 37) were separated from their biological caregiver(s). Of these, 31 were legally adopted and currently living in stable families, and five were living with one of their biological parents. In addition to PTSD, most children had received a range of other DSM diagnoses, including attention deficit disorder/attention deficit/hyperactivity disorder, learning disabilities, depression, anxiety, oppositional defiance, conduct disorder, and bipolar disorder. These diagnoses were not part of the exclusion criteria, nor were they factored into the analysis. According to caregiver report, several children were on medication: stimulants, epileptic, antipsychotic, selective serotonin reuptake inhibitors, and antianxiety. The participants were recruited from the greater Boston area via advertisements in local newspapers, local community programs, flyers, and therapists' referrals.

Table 1
Participants' Demographics

Variable	Total ($N = 37$)	Wait list ($N = 17$)	Neurofeedback ($N = 20$)
Age			
Mean (*SD*)	9.62 (1.87)	9.60 (2.10)	9.65 (1.70)
Gender			
Female	13	8	5
Male	24	9	15
Ethnicity			
Hispanic/Latino	6	2	4
Not Hispanic/Latino	31	15	16
Race			
African American	7	3	4
Caucasian	21	11	10
Multiethnic	6	2	4
Asian	3	1	2
Living situation			
Adopted	28	12	16
Kinship care	3	2	1
Biological parents	6	3	3

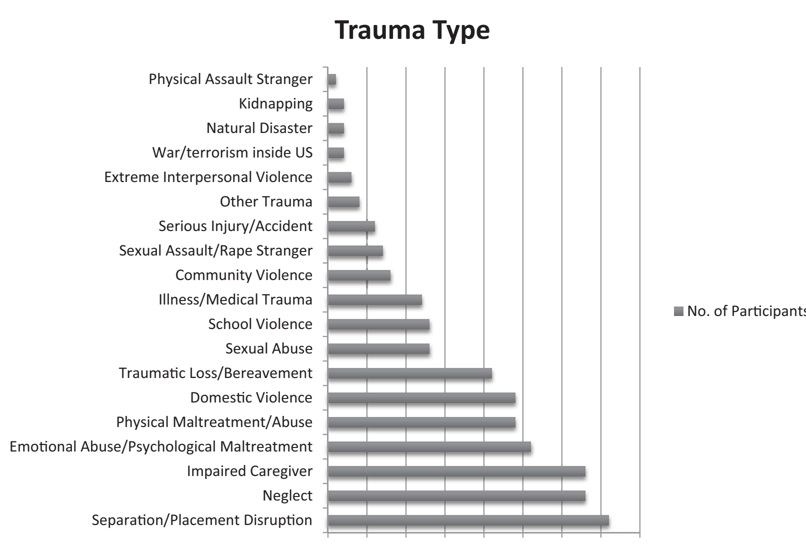

Figure 1. Participants' trauma history. This figure shows the participants' trauma history. Each row represents a different type of trauma. The X-axis shows the number of participants who experienced the trauma. An average of 14 participants experienced one type of trauma. There was an average of seven different types of trauma per participant.

Inclusion criteria. Children aged 6–13 years who met the following criteria were considered for the study: (a) two or more interpersonal traumatic experiences; (b) in weekly individual therapy with the same therapist for at least 3 months prior to study; (c) no medication or psychosocial treatment changes in the past 3 months; (d) clinically significant PTSD on structured assessment or clinically significant symptoms on the Child Behavioral Checklist (CBCL; internalizing or externalizing scales).

Exclusion criteria. Children were excluded from the study if they met any of the following exclusion conditions: (a) history of epilepsy, seizure, or head injury; (b) having received prior NFT for the past 5 years (no child was excluded on the basis of this criteria); (c) currently on benzodiazepines because benzodiazepines are thought to impair learning and memory, for example, the acquisition of new information (Guina & Merrill, 2018); (d) ongoing safety concerns at home; (e) serious suicide attempt in the past 6 months; or (f) psychiatric hospitalization.

Procedure

A flowchart (timeline and number of participants) of the study is shown in Figure 2. After approval by the institutional review board, enrollment consisted of three steps: (1) initial phone conversation with the caregiver; (2) full phone screening with the caregiver; and (3) baseline assessment with the child and his or her caregiver. All caregivers received a detailed explanation about the study and signed an informed consent. The caregiver's baseline assessment consisted of questionnaires about the child's current symptoms, trauma history profile, and demographic and medical history (including medications). Because so many children were adopted, the trauma histories were often incomplete. The child completed self-report questionnaires of current symptoms and computerized assessment to measure executive functioning (NIH Toolbox, 2012).

Participants were randomly assigned to one of the two groups: active NFT or control. Those in the active NFT group received NFT twice a week for 24 sessions over the course of approxi-

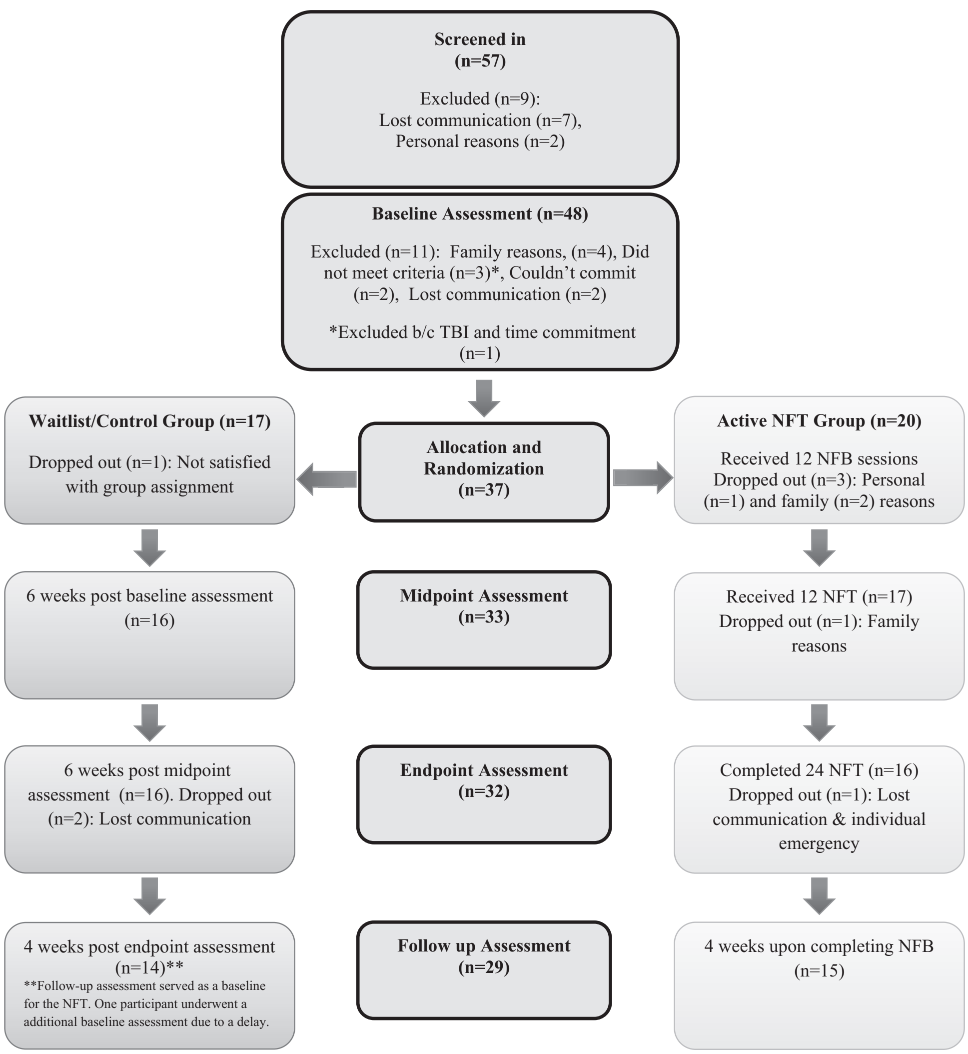

Figure 2. Flow chart. This figure shows the flow chart for the study. NFT = Neurofeedback training.

mately 12 weeks (3 months). The WL group continued to receive treatment as usual; they were assessed with equal frequency as the NFT group and received NFT after the formal end of the study.

Participants underwent four time point assessments over 4 months, including baseline, halfway (approximately 6 weeks after baseline assessment for control group or halfway [12 sessions] for the active NFT group), end point, and 1 month follow-up after end point assessment. The same blind rater completed all assessments.

Baseline assessment included PTSD Reaction Index (PTSD-RI) history, trauma history, and child's demographics. The following measurements were performed during all the formal assessments (see *Measurements* section). The same caregivers completed the CBCL, Behavior Rating Inventory of Executive Function (BRIEF), Trauma Symptom Checklist for Young Children (TSCYC), Children's Alexithymia Measure (CAM), Child Dissociative Checklist, Kiddie Schedule for Affective Disorders and Schizophrenia for School Aged Children (K-SADS), PTSD-RI, and the child completed the Children's Depression Inventory 2, PTSD-RI, K-SADS, and NIH Toolbox cognitive battery. During the NFT periods and after every NFT session, the same caregiver and the child completed a self-report NFT Symptom Checklist questionnaire to track the NFT changes. Caregivers received a compensation of $25 per assessment. Children received a gift card for $5 upon completing the study.

The study was conducted between February 1, 2014, and January 31, 2017, at the Trauma Center at Justice Resource Institute (and was approved by the Justice Resource Institute Institutional Review Board for studies involving human subjects). All assessments were conducted by blinded, graduate-level research staff.

Measurements

1. The CBCL is a well-validated questionnaire that assesses emotional and behavioral problems in school-age children (Achenbach & Rescorla, 2001).

2. The BRIEF is a commonly used assessment of executive functions and self-regulation (Gioia, Isquith, Retzlaff, & Espy, 2002).

3. The TSCYC is a measure of symptoms that young children may present after experiencing a potential trauma (Nilsson, Gustafsson, & Svedin, 2012).

4. The PTSD-RI is a semistructured interview that measures a child's trauma history and determines whether a child's meets *DSM–5* diagnostic criteria for PTSD (Steinberg et al., 2013). The PTSD-RI was completed both by caregivers and children.

5. The K-SADS (for *Diagnostic and Statistical Manual of Mental Disorders*, fourth edition, text revision) is a common semistructured diagnostic interview that incorporates both child and parent reports (Young, Bell, & Fristad, 2016).

6. The CAM is used to screen children with alexithymia or difficulty in recognizing and expressing their feelings (Way et al., 2010).

7. The Child Dissociative Checklist questionnaire that measures dissociative symptoms in children (Putnam, Helmers, & Trickett, 1993).

8. The Children's Depression Inventory 2 is a self-rating scale of severity of depressive and dysthymic symptoms (Kovacs, 1992).

9. NIH Toolbox cognitive battery includes four tests to measure executive function, attention, episodic memory, language, processing speed, and working memory. Both the assessor and child used computers and keyboards (NIH Toolbox, 2012).

10. The Caregiver NFT Symptom Checklist is a self-report questionnaire to track the child's behavior during the course of NFT and developed for this study to accurately and quantitatively measure clinical symptomatology during the course of NFT, which included the following symptoms: attention-focus, mood, sleep, communication-connection, energy, physical symptoms, and individual symptoms. Each symptom was measured on intensity, frequency, and change compared with previous session.

11. The Child NFT Symptom Checklist is a self-report checklist to accurately and quantitatively measure clinical symptoms during NFT.

Neurofeedback Training

NFT was performed with a Spectrum2 amplifier by J&J Engineering Inc. (Greenfield, IN) and EEGer4 Software by EEG Software, LLC (Gainesville, FL). Participants used the games from EEGer4 Software and Zukor Interactive (Las Vegas, NV). The impedance of all electrodes (gold electrodes) were kept under 10 kΩ. All electrodes were placed according to the international 10/20 system. All participants started with a bipolar protocol of T4 as the active site, P4 as the reference site, and the left ear A1 as the ground. The inhibition was 2–4 Hz, 4–7 Hz, and 22–36 Hz with thresholds of 35%, 35%, and 25%, respectively. The reward band was individualized and based on the individual posterior dominant rhythm (PDR). The reward was calculated as the 3-Hz band from 1 Hz below PDR to 1 Hz above PDR. PDR was the 1-Hz band highest amplitude (in microvolts) measured at PZ electrode placement according to the international 10/20 system with eyes closed. The threshold for the reward band was initially set for 65%. The methodology in this study followed the two studies on adults with chronic PTSD (Gapen et al., 2016; van der Kolk et al., 2016), clinical experience, and previous fMRI, positron emission tomography, and Magnetoencephalography (MEG) research that have demonstrated increased right temporal–superior parietal activation in PTSD (Engdahl et al., 2010; Georgopoulos et al., 2010; Kemp et al., 2010), and the impact of traumatic stress on the right amygdala, hippocampal and temporoparietal activation (Teicher et al., 2016).

Adjustments to the protocol were based on caregiver and child reports, NFT Symptom Checklist reports, and clinical judgment. For example, if the caregiver reported significant symptoms worsening for two consecutive sessions and these changes were not attributed to an external source, the reward band was adjusted by 0.5 or 1 Hz.

NFT consisted of 24 sessions, twice a week for 12 weeks, provided by one of two administrators (each child was consistently trained by the same technician). Training sessions were checked weekly for fidelity by other staff members. Training time for each session was 6–18 min. During the session, brain electrical activity was recorded while participants watched a computer game that reflected the status of their EEG activity. If the power of the recorded brain signals at the specific frequencies (bands) were met, that is, above the threshold for the reward band and below the threshold for the inhibition bands, participants were rewarded with audio and visual rewards. They were told that these rewards are good signs and that no specific effort on their part is required because the learning process is beyond conscious control. Participants were also rewarded with small toys as prizes based on their achieving desired EEG changes.

Data Analysis

χ^2 analyses were first conducted to evaluate the impact of NFT on PTSD diagnoses (present/absent) as assessed by K-SADS. Next, piecewise multilevel growth curve modeling (GCM), (Singer & Willett, 2003) was conducted to examine change in identified trauma-related symptoms through the course of treatment. The GCM model was implemented using the MIXED procedure of the Statistical Package for the Social Sciences (Peugh & Enders, 2005) with full maximum-likelihood estimation. Multilevel GCMs have become the standard for analyzing psychotherapy outcome data because of several advantages that this approach offers (including the capacity to handle missing data and unbalanced information, efficient and powerful estimation techniques to include all available data, and modeling flexibility (Singer & Willett, 2003). This approach enabled an analysis of the entire intention-to-treat (ITT) sample without using data imputation procedures. GCM was recommended by the Institute of Medicine (2001) for small clinical trials to maximize data use while obtaining reliable and valid results.

Piecewise growth modeling (Singer & Willett, 2003) examined change during treatment and during follow-up. Two time variables were included in the analyses: The primary time variable began at zero (baseline assessment) and increased by one for subsequent assessments; and a variable coded zero for all the assessments that occurred during treatment and coded one for the follow-up assessment. This model produces three coefficients: The regression intercept represents baseline scores; the first-time parameter for changes during treatment; and the second time parameter for the difference in rate of change during treatment and during the follow-up period.

Reparametrizing the time variables allowed obtaining different information from this same overall model. We examined the impact of treatment condition (NFT vs. WL) by including a dummy-coded treatment variable as predictors of the time parameters. Effect sizes (*d*) for differences in change between conditions were computed by the procedures described by Feingold (2009) producing effect size estimates comparable with those derived from more traditional repeated-measures designs (e.g., repeated-measures ANOVA) with .20, .50. and .80 generally used as indices of small, medium, and large effects, respectively.

Results

The results of a PTSD diagnosis as measured by responses on the K-SADS measurement are shown in Figure 3. Most participants initially met criteria for PTSD; there was no significant difference between WL (13 of 17, 76.5%) and NFT (19 of 20, 95.0%), $\chi^2(1, n = 37) = 2.70$, $p = .100$. At the midpoint, a higher proportion of WL participants (11 of 16, 68.8%) met criteria for PTSD than NFT (six of 17, 35.3%), $\chi^2(1, n = 33) = 3.694$, $p = .055$. At the end point, there was a significant difference between the two groups; a higher proportion of WL participants (10 of 16, 62.5%) met criteria for PTSD than NFT participants (four of 16, 25%), $\chi^2(1, n = 32) = 4.571$, $p = .033$. However, at the 1-month follow-up, the difference between the WL participants who no longer met criteria for PTSD (seven of 14, 50%) and NFT participants (10 of 15, 66.7%) was no longer significant $\chi^2(1, n = 29) = 8.29$, $p = .362$.

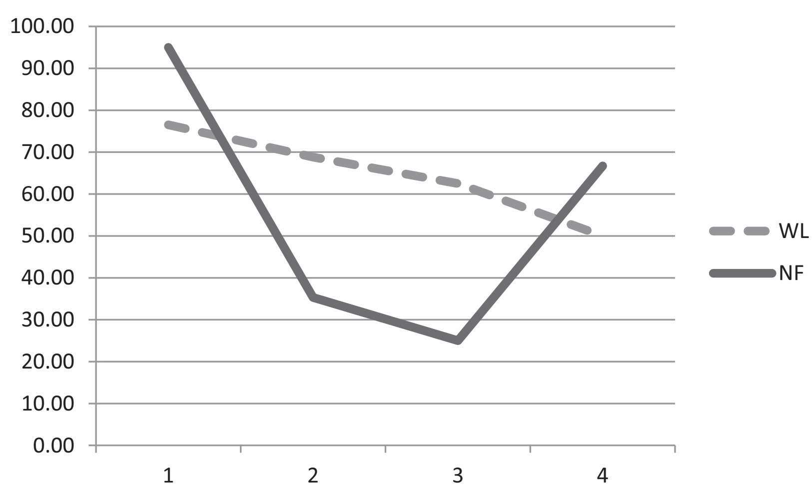

Figure 3. K-SADS scores. This figure shows the K-SADS scores, where the Y-axis shows the four time point assessments and the X-axis shows the percentages of the participants who met criteria for PTSD. Time point 1 is baseline assessment, 2 midpoint assessment, 3 end point assessment, and 4 follow-up assessment. WL = waiting list group; NF = active NFT group neurofeedback group; K-SADS = Kiddie Schedule for Affective Disorders and Schizophrenia for School Aged Children.

Table 2
Pretreatment, Posttreatment, and One-Month Follow-Up Means and Confidence Intervals for Self-Report Measurements

Outcome	Before treatment (*N* = 37) NF = 20, WL = 17 *M* (95% CI)	After treatment (*N* = 32) NF = 16, WL = 16 *M* (95% CI)	One-month follow-up (*N* = 29) NF = 15, WL = 14 *M* (95% CI)
CBCL externalizing			
WL	24.36 (19.91, 28.82)	23.42 (18.84, 27.99)	25.17 (20.13, 30.21)
NF	18.98 (14.87, 23.09)	11.02 (6.70, 15.35)	14.59 (9.81, 19.37)
Difference	−5.39 (−11.45, 0.67)	−12.40 (−18.69, −6.10)	−10.57 (−17.52, −3.63)
Diff *d*	−0.57	−1.16	−0.96
p	.08	.00	.00
CBCL internalizing			
WL	18.41 (13.97, 22.84)	14.81 (10.63, 18.99)	16.74 (12.43, 21.04)
NF	17.58 (13.48, 21.67)	9.94 (5.98, 13.89)	12.93 (8.87, 17.00)
Difference	−0.83 (−6.87, 5.21)	−4.87 (−10.63, 0.88)	−3.80 (−9.73, 2.12)
Diff *d*	−0.09	−0.55	−0.48
p	.78	.095	.201
BRIEF-global executive			
WL	172.29 (162.43, 182.15)	171.34 (160.98, 181.70)	178.80 (167.17, 190.42)
NF	162.56 (153.45, 171.67)	146.59 (136.69, 156.49)	149.85 (138.77, 160.93)
Difference	−9.73 (−23.15, 3.69)	−24.75 (−39.08, −10.43)	−28.95 (−45.01, −12.89)
Diff *d*	−0.49	−1.10	−1.33
p	.15	.001	.001
BRIEF-behavioral regulation			
WL	68.46 (64.10, 72.81)	68.72 (63.65, 73.79)	69.25 (63.58, 74.91)
NF	62.04 (58.02, 66.06)	53.30 (48.47, 58.13)	55.18 (49.83, 60.53)
Difference	−6.42 (−12.35, −0.49)	−15.42 (−22.42, −8.42)	−14.07 (−21.86, −6.28)
Diff *d*	−0.68	−1.33	−1.22
p	.04	<.001	<.001
BRIEF-metacognition			
WL	103.83 (98.86, 110.80)	102.69 (95.97, 109.41)	109.63 (102.32, 116.94)
NF	100.53 (94.09, 106.97)	93.33 (86.93, 99.74)	94.80 (87.83, 101.76)
Difference	−3.30 (−12.79, 6.19)	−9.36 (−18.64, −0.08)	−14.83 (−24.93, −4.73)
Difference *d*	−0.24	−0.65	−1.19
p	.49	.05	.01
CAM-total			
WL	17.15 (13.34, 20.97)	17.14 (13.25, 21.03)	16.71 (12.60, 20.81)
NF	14.40 (10.88, 17.91)	10.51 (6.83, 14.19)	11.84 (7.98, 15.70)
Difference	−2.76 (−7.95, 2.43)	−6.63 (−11.98, −1.28)	−4.87 (−10.50, 0.77)
Diff *d*	−0.35	−0.88	−0.59
p	.288	.016	.088
TSCYC depression			
WL	15.26 (13.23, 17.29)	15.70 (13.61, 17.78)	15.46 (13.05, 17.88)
NF	14.85 (12.98, 16.72)	12.28 (10.27, 14.28)	13.30 (10.98, 15.62)
Difference	−0.41 (−3.17, 2.35)	−3.42 (−6.31, −0.53)	−2.16 (−5.51, 1.19)
Diff *d*	−0.09	−0.81	−0.48
p	.766	.022	.199
TSCYC anxiety			
WL	17.21 (14.89, 19.52)	16.92 (14.56, 19.28)	16.77 (14.14, 19.40)
NF	17.12 (14.98, 19.26)	13.82 (11.56, 16.08)	14.84 (12.33, 17.35)
Difference	−0.09 (−3.24, 3.06)	−3.10 (−6.36, 0.17)	−1.93 (−5.57, 1.71)
Diff *d*	−0.02	−0.62	−0.44
p	.956	.063	.289
TSCYC total			
WL	51.27 (45.70, 56.85)	50.52 (44.53, 56.51)	50.78 (44.09, 57.48)
NF	48.08 (42.93, 53.23)	39.02 (33.31, 44.73)	42.82 (36.46, 49.18)
Difference	−3.19 (−10.78, 4.40)	−11.50 (−19.78, −3.22)	−7.96 (−17.20, 1.27)
Diff *d*	−0.26	−0.89	−0.66
p	.4	.008	.089

Note. WL = wait list condition; NF = neurofeedback condition; one-month follow-up = 1 month after treatment assessment; CI = confidence interval; *d* = effect size indicator with .2, .5, and .8 indicating small, medium, and large effect sizes; diff *d* = difference between WL and NF groups; BRIEF = Behavior Rating Inventory of Executive Function; TSCYC = Trauma Symptom Checklist for Young Children; CAM = Children's Alexithymia Measure; CBCL = Child Behavior Checklist.

The estimation of GCM for each outcome at baseline, end point, and the follow-up assessments with the corresponding change parameters (i.e., pre-end, end–follow-up change) are shown in Tables 2 and 3. A significant effect of treatment condition emerged for all outcomes but one, with effect sizes ranging from −.49 (medium effect) for alexithymia (CAM) to −.96 (large effect) for the behavioral regulation subscale of the BRIEF. Most effect sizes were in the medium-large to large range. The change in the

Table 3
Changes Estimate for Self-Report Measurements Between Pre-Post and Post–Follow-Up

Group	Change pre-post			Change post–follow-up		
	M (95% CI)	*p*	*d*	*M* (95% CI)	*p*	*d*
CBCL externalizing						
WL	−0.23 (−3.42, 2.95)	.880	−0.02	.14 (−2.57, 2.85)	.920	0.02
NF	−7.05 (−10.10, −4.00)	<.001	−0.74	2.50 (−.12, 5.11)	.060	0.26
Difference	−6.82 (−11.23, −2.41)	<.001	−0.72	2.35 (−1.41, 6.12)	.220	0.25
CBCL internalizing						
WL	−3.05 (−5.87, −0.22)	.035	−0.31	0.87 (−1.77, 3.52)	.510	0.09
NF	−7.99 (−10.71, −5.28)	<.001	−0.81	2.66 (0.10, 5.23)	.040	0.27
Difference	−4.95 (−8.86, −1.03)	.014	−0.5	1.79 (−1.90, 5.47)	.340	0.18
BRIEF-global executive						
WL	−0.95 (−8.95, 7.06)	.814	−0.05	7.45 (0.02, 14.89)	.049	0.38
NF	−15.97 (−23.85, −8.10)	<.001	−0.81	3.26 (−3.94, 10.46)	.371	0.16
Difference	−15.02 (−26.25, −3.80)	.009	−0.76	−4.19 (−14.55, 6.16)	.423	−0.21
BRIEF-behavioral regulation						
WL	0.26 (−3.27, 3.80)	.882	0.03	0.52 (−2.95, 4.00)	.765	0.06
NF	−8.74 (−12.24, −5.24)	<.001	−0.93	1.88 (−1.49, 5.25)	.270	0.2
Difference	−9.01 (−13.97, −4.04)	.001	−0.96	1.36 (−3.48, 6.20)	.579	0.14
BRIEF-metacognition						
WL	−1.14 (−6.33, 4.05)	.663	−0.08	6.94 (2.18, 11.70)	.005	0.51
NF	−7.20 (−12.28, −2.11)	.006	−0.53	1.46 (−3.14, 6.07)	.529	0.11
Difference	−6.06 (−13.32, 1.21)	.101	0.44	−5.48 (−12.10, 1.15)	.104	−0.40
CAM total						
WL	−0.01 (−2.42, 2.39)	.991	0.00	−0.43(−2.79, 1.93)	.717	−0.05
NF	−3.89 (−6.26, −1.51)	.002	−0.49	1.33 (−0.96, 3.63)	.251	0.17
Difference	−3.87 (−7.25, −0.49)	.025	−0.49	1.76 (−1.53, 5.06)	.290	0.22
TSCYC depression						
WL	0.44 (−1.42, 2.29)	.639	0.1	−0.23 (−1.90, 1.44)	.782	−0.05
NF	−2.57 (−4.39, −0.76)	.006	−0.59	1.02 (−0.59, 2.64)	.211	0.23
Difference	−3.01 (−5.61, −0.41)	.024	−0.69	1.26 (−1.06, 3.58)	.285	0.29
TSCYC anxiety						
WL	−0.29 (−2.17, 1.59)	.76	−0.06	−0.15 (−1.90, 1.61)	.868	−0.03
NF	−3.30 (−5.15, −1.45)	.001	−0.66	1.02 (−0.68, 2.72)	.235	0.2
Difference	−3.01 (−5.65, −0.37)	.026	−0.60	1.17 (−1.27, 3.61)	.344	0.23
TSCYC total						
WL	−0.75 (−5.12, 3.61)	.732	−0.06	0.26 (−3.81, 4.33)	.897	0.02
NF	−9.06 (−13.37, −4.76)	<.01	−0.75	3.80 (−0.14, 7.74)	.059	0.32
Difference	−8.31 (−14.44, −2.18)	.009	−0.69	3.54 (−2.13, 9.20)	.218	0.29

Note. Pre-post = changes between pretreatment assessment (pre) and immediate posttreatment assessment (post); post–follow-up = changes between posttreatment assessment (post) and 1 month after treatment assessment (follow-up); WL = waiting list group; NF = neurofeedback group; BRIEF = Behavior Rating Inventory of Executive Function; TSCYC = Trauma Symptom Checklist for Young Children; CAM = Children's Alexithymia Measure; CBCL = Child Behavior Checklist.

metacognition subscale of the BRIEF was the only one not statistically significant.

CBCL internalizing showed significant differences between treatment groups at posttreatment. Three outcomes measures (CBCL externalizing, BRIEF global, BRIEF metacognition) remained statistically significant at the follow-up. The effect sizes for differences for outcomes between treatment conditions that no longer exhibited a statistical significance at follow-up were right around or above the cutoff of $d = .50$, which suggests that meaningful treatment effects were maintained, although this study was too underpowered to demonstrate statistical significance at follow-up.

Discussion

This is the first randomized-controlled NFT study to treat children with histories of severe abuse and/or neglect. Twenty-four sessions of NFT significantly reduced the number of the participants who met criteria for PTSD. In addition, NFT significantly reduced dysfunctional behavioral and emotional symptoms, as measured by CBCL externalizing and internalizing, behavioral regulation, the CAM, TSCYC total, and TSCYC anxiety and depression, and improved executive functioning (BRIEF global). Based on these results, NFT has potential to be an effective treatment for polysymptomatic children with histories of severe abuse and neglect.

Poor affect regulation, such as difficulty modulating emotions, disruptive behaviors, and interpersonal involvement is a pervasive problem after early interpersonal trauma (Aroche, Tukelija, & Askovic, 2009; Ford et al., 2013; Lippard et al., 2020). This study suggests that NFT can significantly improve affect regulation, as demonstrated by significant decreases in CBCL scores, and improvement in executive functioning, as indicated in the BRIEF scores. However, whereas 24 sessions of NFT significantly improved the overall mental status of the participants (Table 3, Pre-Post), they continued to be quite symptomatic: For example, parents reported fewer temper tantrums that lasted a shorter time and fewer classroom disruptions, but most problems persisted to a lesser degree. Moreover, the treatment gains had started to revert at the 1-month follow-up assessment (Table 3, Post-Follow-up).

Clearly, 24 sessions were insufficient to produce lasting changes, suggesting that studying longer treatment protocols is indicated. Interestingly, this finding contrasts with the continued improvement in the corresponding study of adults who received 24 NFT sessions (van der Kolk et al., 2016). With histories of severe abuse, neglect, and disrupted attachment relationships, it will be critical to discover optimal treatment protocols and length of NFT to predictably diminish pervasive psychopathology and to maintain improvement.

Another issue that deserves further study is the optimal protocol for this population. In this study the same protocol, P4-T4, was applied to every participant, regardless of age, demographics, attachment status, or abuse and neglect history. To date, there have been no published studies to establish the most effective protocol or the optimal number of sessions for any traumatized population, including adults with PTSD, let alone children with histories of severe abuse and neglect.

One salient issue for this child population is the length of each individual session. Among neurofeedback practitioners an average length of sessions is generally around 30 min for adults for various forms of psychopathology. In this study, we found that most children could not tolerate such lengthy sessions and that the optimal session duration was only 6–12 min. Longer sessions reduced the child's performance, both as measured by EEG activity, and by the children's behavior (parents reported more agitation, aggression, or anxiety). Reducing the length of the session decreased these adverse reactions.

It is interesting that, whereas the NFT focused on changing EEG activity in the right temporoparietal junction (in the hope of decreasing the activity of fear responsivity), the main clinical effects were expressed in improved executive functioning, which is associated with prefrontal activity (Zelazo & Cunningham, 2007). Our clinical experience has shown us that direct training of frontal lobe activity often leads to increased agitation, without improvement in executive functioning. This opens up the possibility that changing fear circuitry may improve higher cortical functions and suggests that future studies of neurofeedback for posttraumatic conditions might want to focus on elucidating ways to alter overall brain circuitry (Lanius, Frewen, Tursich, Jetly, & McKinnon, 2015).

On several occasions, sensitive information was disclosed to the neurofeedback practitioner, for the first time, during the NFT session. This included suicidal ideation, being bullied, hallucinations, and gender identification issues. This was interesting, given that all children currently lived in supportive and stable homes and told us that they had good rapport with their therapists. One possible explanation is that NFT regulates arousal and calms down the fear circuitry (Gapen et al., 2016; van der Kolk et al., 2016), which may make it tolerable for children to talk about sensitive and stressful challenges without getting triggered and overwhelmed. This supports the notion that NFT should be combined with psychotherapy to deal with whatever information is disclosed (Fisher, Lanius, & Frewen, 2016).

Finally, adverse reactions are a natural part of NFT, and even healthy individuals sometimes experience mild side effects to well-accepted or common protocols (Rogel et al., 2015). Thus, we actively tracked changes and attempted to correctly correlate any adverse reactions with NFT, rather than attribute them to external causes (Rogel et al., 2015). Resolving adverse reaction is analogous to the way physicians adjust medications. During the NFT, some participants reported mild adverse reactions, including feeling more anxious or destructible, temporary headaches, or mild sleep disturbances. All adverse reactions were addressed and resolved by switching to a different feedback modality (e.g., change the game), changes in the reward band protocol, and, in one participant, changing the location of the electrodes.

Limitations

This pilot study has several limitations. The first is the limited number of participants ($n = 37$), which reduces the statistical power. This limited the ability to accurately correlate the treatment with the type, age, length of the traumas, gender, living situations, and symptoms. As a group, the children experienced a large number ($n = 19$) of different types of trauma at different stages of development. Almost two thirds of the participants were male. The majority of the participants were adopted ($n = 28$) and only six lived with their biological parent(s). Of these, four were specifically removed from the other parent. During the study all children lived in safe and stable homes. However, because of the removal from their biological parents, the participants' complete trauma history is unknown. All participants attended weekly therapy sessions. They all had their own psychotherapists, without the study controlling the quality of the therapy.

This pilot study leaves numerous questions unanswered. All participants received the same NFT protocol. The protocol was not based on individual differences in brain electrical activity (as measured by quantitative EEG) and did not take the children's clinical symptoms, type of trauma, or age at which the trauma occurred into account. Future studies need to determine the optimal protocols for this population and whether clinical symptomatology, quantitative EEG variables, or self-report are the best guides for successful NFT intervention. Critically, the NFT consisted of only 24 sessions and 1-month follow-up assessment, at which point they showed a regression in the improvement. Therefore, the optimal duration of NFT in this population remains to be determined and what further changes can be expected with more prolonged treatment as well as the potential utility of booster sessions.

Conclusions

This randomized-controlled trial demonstrated that, compared with a treatment-as-usual control group, 24 sessions of NFT led to a significant decrease in PTSD symptomatology in most participants. In addition, it significantly reduced externalizing and internalizing problems and significantly improved executive functioning in children with histories of severe abuse and neglect, who had not benefited from any form of previous therapy. These results need to be followed by future studies with a larger sample size, an exploration of optimal NFT protocols and attention to differential impact of type, and length and age of onset of the trauma(s).

Longer-term NFT administration and longer follow-up assessments are necessary to determine whether NFT gains can be maintained over time and whether booster sessions will be beneficial.

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