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Effectiveness of Neurofeedback in Treating Trauma Symptomatology Among Justice-Involved Adolescents in Residential Treatment

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Abstract

Objective. Adolescents who have experienced complex psychological trauma may incur neurobiological alterations that can be linked to internalizing and externalizing behaviors, while impeding adaptive coping and resolution skills. Scientific advances in the effects of trauma and neuroplasticity in adolescence have the potential to revolutionize interventions for justice-involved youth. The objective of this study was to examine the efficacy of low-resolution electromagnetic tomography (LORETA) *z*-score neurofeedback in decreasing internalizing and externalizing behaviors, as well as trauma symptomatology among justice-involved adolescents with a history of trauma. **Methods.** A secondary analysis of a quasi-experiment was conducted with 41 youth assigned to receive 24 sessions of LORETA *z*-score neurofeedback (LZNF; n = 20) or treatment-as-usual (TAU; n = 21). **Results.** Individual repeated measures analysis of variance (rANOVAs) reveal LZNF efficacy in decreasing dissociation-fantasy scores. **Conclusion.** Implications highlight the potential of expanding brain-based services within the array of treatment options for traumatized youth across child welfare and justice systems.

Keywords: trauma; juvenile justice; youth; adolescent development; neuroscience

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Introduction

The relationship between complex psychological trauma, chronic stress, and brain architecture is complex. Significant adversity can cause developmental disruptions that lead to lifelong impairments in physical and mental health, educational achievement, economic productivity, and longevity (Abram et al., 2013; Dierkhising et al., 2013; Felitti et al., 1998; Lippard & Nemeroff, 2020; Shonkoff et al., 2012). Up to 90% of justice-involved youth living in residential treatment have experienced complex psychological trauma placing them at greater risk for lifelong negative outcomes (Sprague, 2008). Ford and Courtois (2009) define complex psychological trauma as the result of exposure to severe stressors that are chronic, involve harm or abandonment by a caregiver or other responsible adult, and occur during sensitive developmental periods such as adolescence. The neurobiological changes that occur in the central brain and peripheral autonomic nervous systems as a result of childhood complex psychological trauma are likely to increase stress, anger, and impulsivity, while inhibiting youth from engaging in effective coping and problem solving (Ford et al., 2012). In addition, research demonstrates complex psychological trauma exposure as being significantly correlated with high-risk behaviors (D'Andrea et al., 2012). Consequently, treating the effects of childhood complex psychological trauma is essential to youth outcomes and has the potential to break the cycle of youth involvement in the justice system. Focusing on justice-involved youth is specifically important to society as juvenile crime comprises the largest proportion of all crime, with youth being arrested for 37% of all violent crimes and 43% of all property crimes (Belfield et al., 2012).

Research has found the prevalence of complex psychological trauma in youth in residential treatment is high, with rates estimated between 50–71% (Bettmann et al., 2011; Jaycox et al., 2004). Further, Sprague (2008) found that 75% of juvenile justice-involved youth have experienced complex psychological trauma, whereas other studies indicate that 90% of these youth have experienced at least one complex psychological traumatic event (Abram et al., 2013; Dierkhising et al., 2013). Many of these youth have been polyvictimized, meaning they have been affected by multiple traumatic stressors on multiple occasions (Abram et al., 2013; Briggs et al., 2012; Charak et al., 2018; Ford et al., 2013; Musicaro et al., 2019). According to Briggs and colleagues (2012), 92% of youth had been polyvictimized; while Abram et al. (2013) found that 56.8% of youth in juvenile detention have been exposed to traumatic stressors six or more times. Unfortunately, complex psychological trauma may continue in intensive residential treatment or juvenile facilities, as the environment (e.g., staff abuse, peer violence, restraints) may re-expose youth to traumatic stressors (Dierkhising et al., 2014; Mendel, 2011).

By gender, female children experience higher rates of PTSD symptoms compared to male children after experiencing complex trauma (Wamser-Nanney & Cherry, 2018). This remains consistent across the life span, as lifetime PTSD prevalence is higher among women (Kimerling et al., 2018).

Internalizing and Externalizing Behaviors and Complex Psychological Trauma

Research has found a strong positive correlation between trauma exposure and complex psychopathology (Ford et al., 2010; Spinazzola et al., 2018), with many children experiencing symptoms consistent with multiple internalizing and externalizing disorders (Cook et al., 2005; Ford et al., 2009; van den Huevel et al., 2023). Further, adverse childhood experiences (ACEs) research has found that children with four or more ACEs were 36.2 times as likely to have learning or behavior problems compared to those with no ACEs (Burke et al., 2011). Emotional, behavioral, and cognitive dysregulation can lead to internalizing and externalizing symptoms and behaviors, with affect dysregulation being common in both trauma symptomatology and juvenile delinquency (Ford et al., 2006). As adolescents are already at risk of emotional dysregulation given normal adolescent brain development, complex psychological trauma can exacerbate dysregulation leading to worse outcomes.

Neurobiological Impact of Complex Psychological Trauma in Adolescence

Complex psychological trauma that occurs in sensitive developmental periods such as adolescence can have significant impacts on the brain causing loss of brain cells, damage to brain cell connectivity, enlargement or shrinking of certain parts of the brain, and hyperactivity of certain parts of the brain such as the amygdala, hippocampus, and prefrontal cortex—all areas which undergo normal development during adolescence (Blanco et al., 2015; Giedd, 2008; Herringa, 2017). In Teicher and Samson's (2016) review of neurobiological effects of childhood abuse and neglect, they discuss how structural and functional abnormalities previously associated with psychiatric illness may instead be a direct consequence of abuse. Childhood complex trauma can inhibit or delay certain aspects of brain maturation and development, disrupt attachment patterns (Cook et al., 2005), affect reward and motivation (Teicher & Samson, 2016), executive systems (Ford et al., 2013), and diminish the ability to self-regulate (Ford et al., 2005). A dysregulated brain has a diminished ability to respond to specific demands, and the discontinuity of brainwaves can lead to faulty processing and communication between the brain and the nervous system (Hill & Castro, 2009).

Neuroimaging studies on aggressive and violent offenders suggest that violent offenders who have engaged in impulsive acts have lower brain function in the prefrontal cortex (PFC) and medial temporal regions in the brain, which are areas associated with affect and emotion regulation (Bufkin & Luttrell, 2005). Their findings support that negative emotion regulation may lead to an increased risk for externalizing behaviors of aggression and violence.

Further, childhood complex psychological trauma has been found to interfere with arousal and stress-management systems resulting in individuals feeling like they are constantly under threat (Cannon & Hsi, 2016). Research has shown that chronic trauma exposure influences hypothalamic-pituitary-adrenal (HPA) axis functioning and can result in persistent alterations in stress responsivity later in life. When an individual's stress response is chronically activated, the HPA feedback loop can be disrupted resulting in negative changes to psychological, behavioral, biological, and physiological functioning as the body may produce excessive amounts of cortisol leading to inappropriate behavioral responses to small or minor threats (Gunnar & Vasquez, 2006; Lawrence & Scofield, 2024; Schumacher et al., 2019).

The complex effects of adverse experiences and the environment have significant influence on our developing and maturing neural circuits (Bick & Nelson, 2016; Keuroghlian & Knudsen, 2007; Knudsen, 2004; Knudsen et al., 2006; Majdan & Shatz, 2006; McLaughlin et al., 2014). Neuroplasticity or the brain's ability to adapt to past experiences or changes in the environment can occur through reorganization, formation of new neural networks, or changes in the strength of connections (Sharma et al., 2013). One of the most promising aspects of the adolescent brain is the flexibility of its circuitry to adapt and form new connections after experiencing adversity (Giedd, 2015; Kanwal et al., 2016). Thus, targeted interventions based in neuroplasticity that can increase cognitive control and enhance neural regulation, especially in the limbic lobe and PFC, may be effective in treating the dysregulation caused by complex psychological trauma.

Neurofeedback Intervention

An innovative potential intervention is neurofeedback, a form of electroencephalogram (EEG) biofeedback that measures the electrical activity in the brain and can change unwanted patterns that may be contributing to poor physical and mental health (Hill & Castro, 2009). Neurofeedback helps regulate arousal levels and resync a dysregulated brain through real-time, operant conditioning at specific sites of the brain (Pop-Jordanova & Zorcec, 2004), with the amplitude of specific brainwaves being altered to improve speed and functioning (Marzbani et al., 2016).

Neurofeedback has been found to improve neurological functioning (Hill & Castro, 2009). During neurofeedback training, the brain gradually moves out of "park" with the ability to self-regulate after treatment is completed (Hill & Castro, 2009). According to Marzbani et al. (2016), neurofeedback is effective in treating ADHD, schizophrenia, insomnia, learning disabilities, drug addiction, autism, epilepsy, depression, anxiety, and pain management. Other studies have examined the effectiveness of neurofeedback in treating posttraumatic stress disorder (PTSD) symptomatology (Askovic et al., 2023; Bell et al., 2019; du Bois et al., 2021; Foster & Veazy-Morris, 2013; Gapen et al., 2016; Leem et al., 2021; Nicholson et al., 2020; Noohi et al., 2017; Smith, 2008; van der Kolk et al., 2016; Walker, 2009). As neurofeedback focuses on neural regulation and stabilization, its effects in treating PTSD may be more effective than other evidence-based treatments that primarily target processing the trauma narrative and associated emotions (van der Kolk et al., 2016). Prior research shows neurofeedback may be beneficial for those who have been traumatized and are experiencing anxiety (Walker, 2009), dissociation, dysregulation, depression, and other PTSD symptomatology (Bell et al., 2019; Foster & Veazey-Morris, 2013; Gapen et al., 2016; Smith, 2008; van der Kolk et al., 2016).

In van der Kolk et al.'s (2016) study, 24 sessions of neurofeedback led to statistically significant improvements in PTSD symptomatology in adults for which 6 months of trauma-focused psychotherapy had been ineffective. Rogel and colleagues (2020) examined neurofeedback on children with developmental trauma and histories of severe abuse and neglect and found that 24 sessions led to statistically significant decreases in PTSD, internalizing and externalizing behaviors, and improved executive functioning. Similarly, Huang-Storms et al. (2006) study of children aged 6–13 with histories of abuse and neglect found significant results in internalizing and externalizing behaviors, social problems, aggressive behaviors, cognitive dysfunction, delinquent behavior, anxiety and depression, and attention problems after an average of 38 neurofeedback sessions over a time period of 2–8 months. Although neurofeedback has shown promise for PTSD treatment, scant research has explored its effects with adolescents.

Low-Resolution Electromagnetic Topography (LORETA) Z-Score Neurofeedback. LORETA *z*-score is a type of neurofeedback that allows clinicians to target cortical and subcortical structures, providing a comprehensive view of brain functioning. With LORETA *z*-score neurofeedback (LZNF), dysregulation of core neurocognitive networks and patient symptomatology can be linked to a specific anatomical location to train through EEG source localization (Thatcher, 2011; Thatcher et al., 2019). In 2004, Applied Neuroscience, Inc., developed a real-time comparison of EEG to a normative database using LZNF and Gaussian distributions (Thatcher et al., 2019), which allows for a single metric to standardize EEG analyses. The development of the normative database has helped refine neurofeedback protocols. Simply reinforcing brainwaves toward $z = 0$ becomes the common goal, regardless of whether the dysregulation is above or below $z = 0$. Based on which functional hubs or Brodmann areas are dysregulated, neurofeedback can be optimized to increase regulation and network connectivity within those areas, which in turn could reduce PTSD symptoms.

Some studies have shown LZNF can reduce the number of sessions needed for positive clinical outcomes (Wigton, 2013), leading to less financial burden for clients and improvement in symptoms in a shorter amount of time. More research is needed to substantiate these claims (Coben et al., 2019; Reiter et al., 2016). However, if increased studies found LZNF to be more effective in less time than traditional neurofeedback protocols, this form of neurofeedback may be more accessible for clinical populations, especially those who are underserved.

As LZNF aims to reduce dysregulation symptoms and arousal levels caused by alterations in the brain, it may be an effective intervention in reducing internalizing (i.e., anxiety, depression) and externalizing behaviors (i.e., attention, rule-breaking, aggression) among trauma exposed, justice-involved youth with histories of complex psychological trauma. The primary research question was: Is LZNF as treatment for justice-involved adolescents with complex psychological trauma effective in reducing internalizing and externalizing behaviors and trauma symptomatology compared to treatment-as-usual? This question was tested through three main hypotheses for each dependent variable.

1) There will be significant occasion (pretest, midtest, posttest, and follow-up) by group (treatment and TAU) interaction effects on levels of internalizing behaviors.
2) There will be significant occasion (pretest, midtest, posttest, and follow-up) by group (treatment and TAU) interaction effects on levels of externalizing behaviors.
3) There will be significant occasion (pretest, midtest, posttest, and follow-up) by group (treatment and TAU) interaction effects on levels of trauma symptomatology

Methods

This research conducted a secondary data analysis on a quasi-experimental designed dataset with a naturalistic, pretest, multiple posttests sample. Based on the secondary, deidentified analysis, this study was exempt from IRB review. Study participants were justice-involved adolescents receiving evidence-based standard treatment in an intensive residential treatment center (RTC) accredited by the Joint Commission. Informed consents were administered at the RTC at intake. Standard programming includes group, individual, and family therapy, recreation therapy, on-campus education, 24/7 nursing, psychiatric consultation, and life skills. As part of standard care, youth remained on any medications that they were prescribed and had weekly medication management check-ins through the facility. Youth in the control group received standard programming along with qEEG assessments at four measurement time points: baseline, session 12, session 24, and 1-month follow-up. Youth in the treatment group received standard programming, qEEG assessments, and 24 LZNF sessions.

Inclusion Criteria

Youth were 11–18 years old, had a clinically significant history of trauma as measured by the cutoff scores on the Trauma Symptom Checklist for Children Screening Form (TSCC-SF) and psychosocial history, had a history of justice involvement, and had the ability to speak, read, and understand English sufficiently well to consent and complete all study procedures. In addition, youth had to be in the custody of a parent or guardian who could provide informed consent. This age range was chosen for inclusion as adolescence is a critical developmental age for intervention due to the plasticity of the brain during this period (Giedd, 2015). Neuropsychiatric services (NPS) lab staff helped administer the TSCC-SF to determine if youth had clinically significant trauma symptoms and intake staff determined history of traumatic events using the psychosocial history in the electronic health record (EHR). Intake staff also helped identify youth with a history of current or past juvenile justice involvement.

Exclusion Criteria

Youth who were in state custody, who had an anticipated release from the residential program within the next 3 months, or those who displayed current psychotic symptoms or severe developmental disabilities were excluded from participation.

Deidentified data sent to the PI included treatment group (coded with 0 = TAU, 1 = treatment), gender, age, race, all raw and *z*-score metrics for the TSCC and Youth Self-Report (YSR), and brain maps for each time point. Data not provided to the PI included information regarding their medications (type, dosage, etc.) or details of their justice involvement (reasons why, any charges, how long their involvement has been, etc.). If eligible, participants were matched by age, gender, and ethnicity and assigned to either standard programming (n = 21) or standard programming plus LZNF (n = 20). The

TSCC and YSR were administered by NPS lab staff at all time points.

Measures

Biofeedback Certification International Alliance (BCIA)-certified neurofeedback technicians administered standardized behavioral measures, EEG, and neurofeedback interventions in the NPS lab.

Demographics. Demographic data included age, gender (coded as 0 = *male*, 1 = *female*), and race (0 = *African American*, 1 = *White*, and 2 = *Asian*).

Trauma Symptom Checklist for Children (TSCC). The TSCC Screening Form (Briere, 1996) cutoff scores were used to determine inclusion criteria for clinically significant trauma symptoms. The TSCC-SF includes 20 items and two subscales: general trauma (GT; 12 items) and sexual concerns (SC; 8 items). Cutoff scores are based on age (8–12) and gender groups (13–17) for each subscale (Briere, 1996): for males ages 8–12: GT scores ≥16 and SC scores ≥5; males ages 13–17: GT scores ≥14 and SC scores ≥6; females ages 8–12, GT scores ≥16 and SC scores ≥3; females ages 13–17, GT scores ≥18 and SC scores ≥4. Internal consistency is in good-to-excellent range and test-retest reliability was r = .80 for each scale. The full TSCC (Briere, 1996) was used across each measurement time points which is a 54-item self-report measure of posttraumatic stress for children 8–16 years. Youth are asked to rate the frequency of certain thoughts and behaviors on a 4-point scale (0 = *never*, 1 = *sometimes*, 2 = *lots of the time*, and 3 = *almost all the time*). The TSCC includes two validity scales (under-response and hyper-response), six clinical scales (anxiety, depression, anger, posttraumatic stress, dissociation, and sexual concerns), and eight critical items. Subscales for dissociation measure overt-dissociation and dissociation-fantasy. Overt-dissociation involves observable disruptions in memory, identity, or perception, and can include depersonalization (feeling detached from oneself) or derealization (feeling like the world is not real; Choi et al., 2017). Dissociation-fantasy is a more subtle form of dissociation often characterized by excessive daydreaming or pretending to be someone or somewhere else (Dalenberg et al., 2012; Giesbrecht & Merckelbach, 2006). Sample items include "worrying about things" and "feeling mad." Cronbach's alpha for the TSCC was α = .732.

Youth Self-Report (YSR). The YSR (Achenbach & Rescorla, 2001) consists of 112 items designed to measure internalizing behaviors such as anxious depressed or withdrawn depression, and externalizing behaviors such as rule-breaking, aggressive behavior and DSM-oriented scales (e.g., oppositional defiant and conduct problems). Items are scored on a 3-point Likert scale (0 = *absent*, 1 = *occurs sometimes*, 2 = *occurs often*). A sample item on the YSR is "Hangs around with others who get in trouble." The internalizing subscale of the YSR has a Cronbach's alpha of α = .60 and the externalizing subscale of the YSR has a Cronbach's alpha of α = .59. As this was a preliminary study, only the internalizing, externalizing, and total YSR scores were analyzed to reduce the risk of false positives.

EEG Acquisition and Neurofeedback Intervention

The NPS director, a BCIA-certified fellow, analyzed all EEG metrics and developed individualized neurofeedback protocols for participants. BrainMaster Discovery 24 amplifiers were used to collect EEG data with NeuroGuide being used for editing EEG and developing qEEG findings. The reference for normality in NeuroGuide is based on other participants of that age. BrainMaster Atlantis 2x2 was used for neurofeedback sessions. An individualized LZNF protocol was developed for each subject based on their baseline EEG to identify the area(s) of the brain exhibiting the most atypical activity and the specific brainwaves that needed to be trained towards normality (z = 0). For all subjects, the common 10/20 system combined with qEEG findings was used. The most common training sites included Cz, F3/F4, Fz, Pz, and C3/C4, with common protocols involving (a) uptraining alpha (8–12 Hz) and downtraining beta (12–30 Hz) activity and (b) downtraining theta (4–8 Hz) and uptraining beta (12–30 Hz) activity.

During neurofeedback, the subject chose games developed through the brain-computer interface in BrainMaster that provided both auditory and visual feedback when the brainwaves matched the thresholds set in each protocol. An example of a game is an animated race where the participant's car only moved when their brain signals were operating within the limits set in their protocol. Thus, the participant learned how to control and interact with the game as their brain waves adjusted to the thresholds. Subjects received three 30-min sessions per week, for a total of 24 neurofeedback sessions. Youth in the study did not report any adverse reactions from the intervention.

Statistical Analysis

Data from standardized behavioral measures was securely stored on a password protected computer in an encrypted Excel sheet for deidentified analysis. EEG data were deidentified, coded, and provided to the PI on a flash drive. IBM SPSS v.29 was used for all statistical analyses. Descriptive statistics and bivariate analyses with demographic variables and pretest scores were conducted. For multivariate analyses, repeated measures analysis of variance (RANOVA) was chosen as it allows the researcher to measure the occasion effect (within-subjects effect), group effect (between-within-subjects effect), and the interaction effect (occasion by group effect). RANOVA has several advantages as it controls for errors due to differences between-subjects, which in turn extracts within-subjects variation, and reduces the error variance, and thus, increases the power in testing the null hypothesis (Abu-Bader, 2016). For any pretest scores significantly different between groups, RANCOVAs were conducted with pretest scores as covariates. Missing data was handled by multiple imputation.

Results

Descriptive Statistics

In the treatment group, 10 youth (50.0%) were 11–13 years old and 10 youth (50%) were 14–16 years old. In the control group, 15 youth (71.4%) were 11–13 years old, and six youth (28.6%) were 14–16 years old. There were 11 females (55.0%) and 9 males (45.0%) in the treatment group. In the control group, there were 13 females (61.90%) and 8 males (38.10%). Half of the participants in the treatment group, (n = 10, 50.0%) identified as white. In the control group, over half (52.38%) identified as African American, and nearly half youth (47.62%) identified as white (see Appendix: Table A1 for descriptive statistics). In the treatment group, there was a 100% retention rate at posttest, but a 76% retention rate at 1-month follow up due to five youth discharging prior to study completion. In the control group, there was a 100% retention rate at all four time points. All youth met inclusion criteria with clinically significant TSCC-SF cutoff scores (see Appendix: Table A1).

Individual t-tests were conducted to examine any gender differences in pretest TSCC-SF, TSCC, and YSR scores. There was a statistically significant difference by gender for depression scores at baseline (t = −3.310; p > .05). Females reported higher depression scores at baseline ($\bar{X}$ = 74.21, SD = 10.16) than males ($\bar{X}$ = 65.47, SD = 6.73). There was a statistically significant difference by gender for sexual concerns scores at baseline (t = 6.75; p > .001). Males reported higher sexual concerns scores ($\bar{X}$ = 21.59, SD = 3.54) than females ($\bar{X}$ = 14.38, SD = 3.25). One-way ANOVAs were conducted to examine any differences in pretest TSCC and YSR scores by race/ethnicity and no significant differences were found.

Independent t-tests were conducted to examine any differences between group regarding the general trauma and sexual concern subscales of the TSCC-SF and all baseline measures for the TSCC and YSR. There was a statistically significant difference by group for externalizing behavior scores at baseline (t = −3.221; p > .05). Those in the treatment group reported higher externalizing behavior scores ($\bar{X}$ = 70.0, SD = 4.26) than those in the control group ($\bar{X}$ = 64.86, SD = 5.88). There was a statistically significant difference by group for sexual concerns scores at baseline (t = 2.244; p > .05). Those in the control group reported higher sexual concerns scores ($\bar{X}$ = 67.62, SD = 7.39) than those in the treatment group ($\bar{X}$ = 62.20, SD = 8.07). Due to the pretest differences for these two scales, ANCOVAs were run with the pretest as a covariate to determine intervention effects. For both sexual concerns and externalizing behaviors, there was no significant intervention effects over time when controlling for pretest scores.

RANOVA Interaction Effects. The results of the two-way RANOVA tests of within-subjects effects showed significant interaction effects for the dissociation-fantasy subscale of the TSCC ($F_{(df\ =\ 3,\ 102)}$ = 7.083, p < .001, η^2 = 0.172). See Appendix: Figure A1 depicting interaction effects.

Table 1
Summary Statistics for YSR Subscale Interaction Effects

Subscales	Treatment Group Mean *T* Score (*SD*)	Control Group Mean *T* Score (*SD*)	*p*	η^2
Internalizing Behaviors			.499	.684
Pretest	64.10 (6.92)	66.90 (4.48)		
Midpoint	64.90 (7.17)	65.48 (5.21)		
Posttest	65.30 (6.85)	67.86 (6.51)		
Follow-up	62.60 (5.23)	64.19 (6.26)		
Externalizing Behaviors			.129	.060
Pretest	70.00 (4.26)	64.86 (5.88)		
Midpoint	69.30 (4.55)	65.05 (4.80)		
Posttest	65.35 (4.31)	66.14 (4.36)		
Follow-up	64.07 (4.51)	64.62 (4.48)		
YSR Total Score			.332	.033
Pretest	67.90 (4.14)	66.62 (6.02)		
Midpoint	65.35 (5.66)	67.38 (5.89)		
Posttest	63.50 (5.92)	65.05 (6.70)		
Follow-up	61.80 (5.33)	64.67 (5.33)		

Table 2
Summary Statistics for TSCC Subscale Interaction Effects

Subscales	Treatment Group Mean *T* Score (*SD*)	Control Group Mean *T* Score (*SD*)	*p*	η^2
Anxiety			.083	.063
Pretest	71.10 (13.28)	69.67 (9.22)		
Midpoint	68.30 (10.00)	69.67 (10.24)		
Posttest	66.90 (8.58)	69.71 (8.64)		
Follow-up	65.47 (8.43)	68.71 (7.18)		
Depression			.311	.034
Pretest	72.55 (11.12)	68.74 (8.24)		
Midpoint	69.60 (9.04)	68.95 (11.39)		
Posttest	66.35 (8.29)	67.76 (9.95)		
Follow-up	64.73 (7.77)	65.05 (8.25)		

Table 2
Summary Statistics for TSCC Subscale Interaction Effects

Subscales	Treatment Group Mean *T* Score (*SD*)	Control Group Mean *T* Score (*SD*)	*p*	η^2
Anger			.053	.072
Pretest	68.45 (8.45)	68.74 (8.24)		
Midpoint	65.45 (8.20)	68.95 (11.39)		
Posttest	64.45 (5.74)	67.76 (9.95)		
Follow-up	63.60 (5.18)	65.05 (8.25)		
Posttraumatic Stress			.191	.048
Pretest	70.15 (13.09)	68.43 (9.65)		
Midpoint	67.60 (11.16)	71.51 (10.86)		
Posttest	66.20 (10.10)	69.95 (10.37)		
Follow-up	66.08 (10.61)	69.00 (8.85)		
Dissociation			.305	.035
Pretest	69.30 (13.62)	68.76 (8.07)		
Midpoint	67.80 (9.42)	69.62 (12.56)		
Posttest	66.35 (8.99)	70.90 (12.17)		
Follow-up	63.93 (7.77)	67.05 (10.44)		
Dissociation-Overt			.355	.033
Pretest	67.65 (11.13)	71.81 (11.71)		
Midpoint	66.00 (9.10)	71.00 (8.78)		
Posttest	65.30 (8.86)	65.48 (7.90)		
Follow-up	65.46 (10.15)	64.95 (7.34)		
Dissociation-Fantasy			.001*	.173
Pretest	70.95 (9.67)	65.29 (9.17)		
Midpoint	68.60 (8.49)	68.14 (10.22)		
Posttest	65.25 (6.81)	67.19 (9.72)		
Follow-up	64.07 (7.07)	66.71 (8.50)		
Sexual Concerns			.684	.014
Pretest	62.20 (8.07)	67.62 (7.39)		
Midpoint	61.30 (6.45)	66.0 (7.64)		
Posttest	61.55 (6.20)	66.62 (9.84)		
Follow-up	59.47 (5.84)	66.81 (9.97)		

Table 2
Summary Statistics for TSCC Subscale Interaction Effects

Subscales	Treatment Group Mean *T* Score (*SD*)	Control Group Mean *T* Score (*SD*)	*p*	η²
Sexual Concerns-Preoccupation			.896	.006
Pretest	64.75 (7.50)	65.95 (7.95)		
Midpoint	65.45 (7.25)	65.43 (7.83)		
Posttest	65.85 (8.31)	66.19 (6.85)		
Follow-up	65.47 (8.43)	67.14 (8.97)		
Sexual Concerns-Distress			.909	.005
Pretest	67.50 (9.99)	68.67 (8.21)		
Midpoint	67.05 (8.74)	67.10 (10.68)		
Posttest	66.10 (7.82)	67.43 (8.73)		
Follow-up	63.53 (6.01)	64.57 (8.67)		

Note. * = $p < .010$.

Discussion

This study explored the use of neurofeedback in treating trauma symptomatology among traumatized youth with histories of justice involvement in intensive residential treatment. All youth in the study had clinically significant trauma symptoms as measured by the TSCC-SF cutoff scores. By gender, there were higher rates of depression among females than males. It was surprising that the PTS subscale was not significant by gender as prior research supports females experience higher rates of PTSD symptoms (Wamser-Nanney & Cherry, 2018). Additionally, we found that males reported higher rates of sexual concerns than females, which was in contrast to previous studies (Wamser-Nanney & Cherry, 2018) and surprising as males typically under-report sexual concerns compared to females (Holmes & Slap, 1998). The lack of gender differences in these results may be attributed to the small sample size.

The primary objective of the study was to test the hypothesis that there is significant occasion (pretest, midtest, posttest, and follow-up) by group (treatment and TAU) interaction effects on levels of internalizing behaviors, externalizing behaviors, and trauma symptomatology. This study found significant interaction effects for one TSCC subscale, with the treatment group showing significantly decreased dissociation-fantasy scores over time compared to the TAU group. The interaction between group and time accounted for 17.2% of the variance in dissociation-fantasy scores. This result suggests that LZNF may help traumatized youth cope without resorting to fantasizing. In Flaherty's (2017) study, youth offenders with crimes against persons had significantly higher rates of dissociation-fantasy scores than those with crimes against property or drug offenses. Their study highlights the importance of treating fantasy subtypes of dissociation as a prevention strategy for criminal behaviors.

There were no significant interaction effects for internalizing or externalizing behaviors. Although the effects were not statistically significant for externalizing behaviors, and the anxiety and PTS subscales of the TSCC, there was an overall reduction in these scores for the intervention group but not for TAU. The failure to achieve statistical significance may be due to low power given the small sample size, wide variability in scores, and the loss of some treatment participants to follow-up.

Previous literature has cited positive effects of neurofeedback on many PTS symptoms (Huang-Storms et al., 2006; Rogel et al., 2020; van der Kolk et al., 2016). However, protocols used in the studies differed from the LORETA *z*-score training employed in this study. Rogel et al. (2020) and van der Kolk et al. (2016) both employed sequential placement of electrodes with active sites at T4 with reference at P4 for adults, whereas Huang-Storms et al. (2006) employed individualized protocols with children. Given these differences, future research with larger sample sizes should compare effects based on protocols and the type of neurofeedback modality used.

Limitations

This study has several limitations. First, the study design lacks a randomized control group, which is challenging as it is unethical to deny treatment to any youth within the care of the facility. However, matching was used based on admission criteria and criteria for brain-based services to control for any confounding variables or differences that may be present in the groups. In addition, there was a small sample size limiting our ability to fully examine differences by gender identity and ethnicity. Although the study sample was diverse with 54% identifying as White, 43% identifying as African American, and 0.5% identifying as Asian, prior research demonstrates the overrepresentation of minority groups in residential facilities and the juvenile justice system (Hockenberry, 2020). Thus, future research needs to draw on larger, more diverse samples and should seek to intentionally recruit more than these three race/ethnicities to better identify and represent the true population in these settings. Using strategies derived from community-based participatory research, such as incorporating the youth at every stage of the planning and development, may increase buy-in and willingness of these marginalized groups to engage in research (Collins et al., 2018).

Future studies may want to include more specific screening measures of mental health symptomatology such as depression and anxiety using the Patient Health Questionnaire for Adolescents (PHQ-A) or Generalized Anxiety Disorder-7 (GAD-7) scales. Although the PHQ-A and GAD-7 are limited screening tools, they can provide more detailed symptomatology information compared to the subscales of the YSR and are still accessible and easy to administer within community-based settings.

Implications and Recommendations

This study promotes collaborative and interdisciplinary research that integrates neuroscience, development, psychology, and social work. Findings suggest that neurofeedback may be an additional intervention for justice-involved youth with complex psychological trauma histories who are in residential treatment. Future research should employ randomized controlled trial designs with this population. Additionally, qualitative data from both the researchers' and staff's observations throughout the study could provide a different and unique perspective to the observed changes in clients.

Longitudinal studies are also warranted to examine how the manifestation of delinquent behaviors, mental health disorders, and trauma symptomatology changes from onset of trauma through early adulthood. This longitudinal data could help provide increased support and adaptation of the trauma coping model (Ford, 2002; Ford et al., 2006; Ford et al., 2009). Future studies should adapt the number of neurofeedback sessions conducted as well as the follow-up measurement to assess for the sustainability of effect and assess recidivism rates.

Increased research is needed comparing the clinical efficacy of various types of neurofeedback (i.e., LORETA neurofeedback vs. traditional methods of neurofeedback) and the training protocols administered for each. Although some researchers suggest LORETA neurofeedback can lead to less sessions, making it a more affordable option for clients (Wigton, 2013), very few rigorous studies exist testing the efficacy of LORETA neurofeedback with clinical populations. A systematic review by Coben et al. (2019) found only three research studies evaluating the effects of LORETA neurofeedback with clinical populations and appropriate comparison groups and concluded that these methods need to be replicated in different populations with rigorous superiority trials conducted to determine its clinical efficacy.

Further, incorporating neuroscience techniques such as neuroimaging and neurofeedback by researching them within the greater context of adolescent development with the addition of biomarkers (i.e., stress hormones) and behavioral markers (i.e., treatment adherence) can provide a more comprehensive view of overall brain functioning and allow clinicians to target specific cortical and subcortical areas of the brain with various behaviors.

Conclusion

This study examined the effects of neurofeedback on justice-involved youth's trauma symptomatology and internalizing and externalizing behaviors. Although exploratory in nature, preliminary results of the study identified that neurofeedback was efficacious in treating dissociation-fantasy scores of justice-involved youth in residential treatment. More rigorous empirical evidence with a larger sample size is needed to support the expansion of neurofeedback as a potential intervention for traumatized youth in child welfare and juvenile justice systems.

Author Disclosure

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Appendix

Table A1
Descriptive Statistics of Sample

Variables	Treatment Group		Control Group	
Age				
11	3		5	
12	2		6	
13	5		4	
14	4		3	
15	3		1	
16	3		2	
(11–13)	10		15	
(14–16)	10		6	
Mean (*SD*)	13.55 (1.64)		12.76 (1.56)	
Gender				
Female	11		13	
Male	9		8	
Race/Ethnicity				
African American	8		11	
Asian	2		0	
White	10		10	
TSCC-SF Raw Scores General Trauma	**Age 8–12**	**Age 13–17**	**Age 8–12**	**Age 13–17**
Female	16.67 (4.93) (*n* = 3)	21.25 (2.71) (*n* = 8)	24.67 (7.26) (*n* = 6)	26.0 (3.46) (*n* = 7)
Male	25.0 (1.41) (*n* = 2)	22.14 (4.38) (*n* = 7)	22.0 (3.16) (*n* = 5)	19.67 (0.58) (*n* = 3)
Sexual Concerns				
Female	12.33 (3.51) (*n* = 3)	15.0 (2.51) (*n* = 8)	14.83 (3.97) (*n* = 6)	14.14 (3.63) (*n* = 7)
Male	21.0 (1.41) (*n* = 2)	21.71 (4.19) (*n* = 7)	21.6 (4.10) (*n* = 5)	21.67 (3.51) (*n* = 3)

Figure A1. *Interaction Effect: TSCC Dissociation Fantasy Subscale.*