Live Z-Score Neurofeedback Training for PTSD: A Feasibility and Acceptability Study

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Abstract: Individuals with traumatic experiences may develop symptoms of post-traumatic stress disorder (PTSD) and co-morbid disorders, such as anxiety disorders, major depression, and substance use disorder. Although exposure therapy is considered the “gold standard” for the treatment of PTSD, dropout rates and patient distress are relatively high. One promising approach is live Z-score neurofeedback (ZNF) training, but clinical evidence is sparse. Thus, the current study aimed to evaluate the feasibility and acceptability of ZNF training among individuals with PTSD. After undergoing a diagnostic interview utilizing the MINI Neuropsychiatric Interview, nine patients with PTSD (7 females; mean age = 20.75 [SD = 2.38]) completed ten ZNF sessions, lasting 20 min each, and the PCL-5 at pre- and post-treatment. Over the course of the study, only a few minor study disruptions, adverse events, and patient complaints were reported, and participants rated high on feasibility and acceptability. Results from repeated measures ANOVAs suggest significant improvements in overall PTSD symptoms. Although these findings need to be replicated in larger samples with active control groups, the current study provides support that ZNF is a safe, acceptable, and potentially effective treatment for PTSD.

Keywords: PTSD; trauma; neurofeedback

1. Introduction

Post-traumatic stress disorder (PTSD) is a debilitating mental health condition following traumatic events involving death, threatened death, serious injury, or sexual violence [1]. According to the National Comorbidity Survey, approximately 60% of people in the US are estimated to experience at least one potentially traumatic event in their lifetime, and the estimated lifetime prevalence of PTSD was 7.8% [2]. The sequelae of exposure to a traumatic event are far-reaching. Major depressive disorder, other anxiety disorders, and substance use disorders are highly co-morbid among people with PTSD [3]. Additionally, functional impairment, low quality of life, poor physical health, and substantial financial burden on the survivors and caregivers are frequently associated with trauma exposure [4–6].

One of the most effective treatments for PTSD is exposure therapy, including prolonged exposure (PE) and cognitive processing therapy (CPT) [7–9]. Recent meta-analyses on psychological interventions for PTSD suggest that exposure therapy demonstrated superior efficacy in reducing symptoms associated with PTSD compared to waitlist and treatment-as-usual [8,10]. Despite the strong clinical evidence, exposure therapy poses significant challenges. In a study involving 796 veterans with PTSD, only 11.4% initiated exposure therapy even though their therapists were trained in PE or CPT [11]. Furthermore, dropout rates among patients who receive exposure therapy tend to be high, ranging between 21 and 50% [11–13]. Emotional distress when confronting trauma-related images, memories, and situations and the fear of the worsening of the symptoms contribute to low initiation and high dropout rates [14,15]. Therefore, an alternative to exposure therapy is needed that can improve patient retention and in-session discomfort.
Neurofeedback (NF) is an emerging approach to treating PTSD symptoms. Based on operant conditioning, NF promotes self-regulation of brain activities, which in turn may lead to improvement in mental health conditions. Since NF does not require the revisiting of traumatic experiences, patients can receive care without emotional distress and thus are more likely to stay in treatment [12]. NF has been applied to the treatment of a wide range of mental disorders, such as depression, anxiety disorders, attention deficit hyperactivity disorder, and PTSD [12,16–18]. Although NF was found to be potentially effective in treating PTSD symptoms, the current literature lacks clear evidence from methodologically sound clinical trials [12].

Previous treatment outcome studies mainly focused on targeting power in alpha and/or theta frequencies as well as sensorimotor rhythm (SMR) to induce a relaxed mental state and improve attention while reducing motor activity [19–21]. As a new method, live Z-score NF (ZNF) has been gaining ground over the past decade. Unlike the conventional NF, the ZNF system outputs real-time Z-scores, the degree to which treatment parameters deviate from an age- and sex-matched normative database, and guides the patient into a desired mental state via auditory or visual feedback [22]. The literature documents the preliminary efficacy of ZNF for ADHD, anxiety, and depression [23,24]. To our knowledge, there is only one controlled study where the effectiveness of low-resolution electromagnetic tomography analysis (LORETA) ZNF and heart rate variability biofeedback was compared [25]. The authors reported that the ZNF group showed large reductions in the symptoms of PTSD and anxiety ($d = 2.09$ and 2.13, respectively) [25]. Despite the large effect sizes, this study may suffer from poor internal validity due to the application of individualized training protocols, and the diagnostic status of the participants was inferred from a self-report questionnaire rather than verified with a clinical interview. Thus, further research is needed to evaluate the acceptability and efficacy of ZNF.

The current study aims to evaluate the feasibility, acceptability, and initial treatment efficacy of 10-session ZNF training. To achieve these aims, we developed three hypotheses to test. First, the study protocol would be feasible to implement with a low dropout rate (i.e., less than 30%). Second, at least 65% of the participants would rate ZNF training as safe and acceptable. Finally, the severity of PTSD symptoms would be significantly reduced following ZNF training.

2. Materials and Methods

2.1. Participants

Twelve individuals with PTSD were recruited from a mid-sized university in the southeast. Participants had a mean age of 23.08 (SD = 7.88). The sample was 16.7% male, 91.7% Caucasian, and 8.3% African American. Participants reported experiencing the following index traumas: sexual violence (75.5%), witnessing a sudden and violent death of a family member (16.7%), and witnessing a serious injury and self-mutilation of a family member (8.3%). 66.7% of participants reported taking medications, such as anti-depressants, anxiolytics, or mood stabilizers, to cope with PTSD-related symptoms. After administering the clinical interview, we found that 91.7% of participants had at least one co-morbid disorder, including major depressive disorder, panic disorder, agoraphobia, and substance use disorder. During the study, three participants dropped out due to schedule conflicts, the end of the semester, or a family emergency, and the mean number of sessions among those dropouts was 4.33, ranging between 2 and 6. This left nine cases for data analysis.

2.2. Measures

Post-traumatic Stress Disorder Checklist for DSM-5 (PCL-5) [26]. The PCL-5 is one of the most widely used self-report measures for PTSD symptoms [27]. The scale consists of 20 items, which are rated on a 5-point Likert scale from 0 (“not at all”) to 4 (“extremely”). This multifaceted scale has four subscales (Reexperiencing, Avoidance, Negative Cognitions and Mood, and Arousal), which correspond to the symptom clusters of the DSM-5. The psychometric properties of the PCL-5 have been well validated in different populations,
with internal consistency ranging between 0.90 and 0.96 (Cronbach’s $\alpha = 0.87$ in the current sample) and test–retest reliability ranging between 0.66 and 0.91 [26,28,29]. In the current study, both total and subscale scores were used to determine the overall and cluster-level severity of PTSD symptoms, respectively.

2.3. NF Training

NF training was performed using the BrainAvatar software (version 4.7.5.906) and the 19-channel BrainMaster Discovery amplifier (Brainmaster Technologies Inc., Bedford, OH, USA) with the linked reference electrodes to the ears and the ground electrode at Fpz. Electrodes were positioned according to the international 10–20 system, and the training sites (i.e., F3, F4, P3, and P4) were consistent across all participants. These electrode sites were chosen to maximize the global modulation of brain activities and minimize the influence of muscle and eye movement artifacts [17,23]. The training protocol involved the modulation of absolute power, relative power, phase, and coherence for delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), low beta (12–15 Hz), and high beta (15–30 Hz) [30]. The raw EEG data were bandpass filtered between 0.5 and 50 Hz, and impedances were maintained below 10 kOhms.

In the current study, a PZOKUL (i.e., Percentage of Z-score Ok Upper and Lower thresholds) protocol from BrainMaster Technologies Inc. was employed. Real-time Z-scores were computed by comparing the treatment metrics (absolute power, relative power, phase, and coherence) at each electrode site with the “qEEG Pro” normative database [31–33]. The database consists of 1482 (955 males and 527 females) and 1232 (799 males and 432 females) participants in eyes-open and eyes-closed conditions, respectively [33]. The age ranged between 6 and 83, and the database was stratified by age [33]. The upper and lower thresholds were set at $+1.5$ and $-1.5$, respectively, and thus, participants received a visual reward when more than 50% of Z-scores fell in the target range between $-1.5$ and $1.5$ [23]. Each participant chose their preferred movie or TV show in order to maximize the reinforcing value of the visual reward [23,34]. To provide visual feedback, a dimmer was overlaid on the video screen and became clear when at least 50% of Z-scores fell within the target range ($\pm 1.5$), while it became opaque when more than 50% of Z-scores deviated from the target range.

2.4. Procedure

After providing informed consent, participants completed the initial assessment. To verify the diagnostic status of participants, three graduate students performed a structured clinical interview using the MINI Neuropsychiatric Interview [35]. Participants then completed the PCL-5 and provided demographic information online via Qualtrics. Following the initial assessment, participants received 10 ZNF sessions, 2–3 times per week, with each session lasting 20 min. After a baseline EEG signal was checked for data quality, participants were asked to put on headphones, sit quietly with minimal body movements, and watch the movie of their choice. While watching a movie during a treatment session, participants were instructed to pay attention to visual feedback and maintain their mental state in such a way that the dimmer would stay clear as long as possible. For the final assessment, participants completed the PCL-5 and an exit survey where they reported the strengths and weaknesses of the ZNF training. Participants were compensated with a $60 Amazon.com gift card for participating in this study. The study protocol was approved by the university’s Institutional Review Board (22-158).

3. Results

3.1. Feasibility

Out of twelve, nine participants completed ten sessions of neurofeedback training and three assessment sessions successfully. The mean time to complete treatment was 41.03 days (SD = 11.57), and the mean absence and reschedule frequency was 1.56 (SD = 1.24). As shown in Table 1, 89% of participants reported that they understood the general proce-
dures and treatment mechanisms of neurofeedback training. All participants expressed their confidence in following the neurofeedback training protocol as intended. Over the course of the study, two minor disruptions in administering neurofeedback sessions were reported: one due to poor EEG data quality and the other due to an EEG cap malfunction. Overall, these results suggest that Z-score neurofeedback training is feasible among people with PTSD.

Table 1. Participant feasibility and acceptability ratings.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I understand the general procedures of neurofeedback training and how it works</td>
<td>4.67 (1.00)</td>
</tr>
<tr>
<td>I was able to complete neurofeedback training and perform the tasks as suggested by the study personnel</td>
<td>5.33 (0.87)</td>
</tr>
<tr>
<td>Neurofeedback training is burdensome in terms of time and effort</td>
<td>1.22 (1.39)</td>
</tr>
<tr>
<td>Neurofeedback training raises ethical concerns</td>
<td>0.33 (0.71)</td>
</tr>
<tr>
<td>Neurofeedback training is safe</td>
<td>5.56 (0.88)</td>
</tr>
<tr>
<td>Neurofeedback training is effective in addressing trauma symptoms and related issues</td>
<td>4.44 (1.24)</td>
</tr>
<tr>
<td>I am satisfied with the neurofeedback training</td>
<td>5.33 (1.12)</td>
</tr>
<tr>
<td>I would recommend neurofeedback training for people with PTSD</td>
<td>5.11 (1.36)</td>
</tr>
</tbody>
</table>

Response options range from 0 (“very untrue”) to 6 (“very true”).

3.2. Acceptability

Participant responses to the acceptability measure are shown in Table 1. Participant burden in terms of time and effort was low, with a mean rating of 1.22 (SD = 1.39). None of the participants reported any safety and ethical concerns. Efficacy ratings were also high, such that 78% of participants endorsed at least moderate levels of treatment efficacy. Furthermore, 89% of participants reported satisfaction with neurofeedback training, with a mean rating of 5.33 (SD = 1.12), and 78% of participants replied that they would recommend neurofeedback training for people with PTSD. When asked about adverse events and the worsening of pre-existing conditions following neurofeedback training, two participants reported experiencing headaches, muscle twitches, and difficulty switching attention, all of which lasted temporarily and subsided over time. Overall, these results suggest that Z-score neurofeedback training is safe and acceptable.

3.3. Preliminary Efficacy

To evaluate the preliminary efficacy, paired-sample t tests were performed on the PCL-5 and its subscales. As shown in Table 2, overall PTSD symptoms were significantly reduced from pre- to post-treatment, \( t(8) = 3.43, p = 0.009 \). At the cluster level, the severity of Reexperience, Negative Cognitions and Mood, and Arousal symptoms significantly decreased following the neurofeedback training (all \( p \)'s < 0.05). These results suggest that Z-score neurofeedback training is potentially effective in ameliorating symptoms associated with PTSD.

Table 2. Pre- and Post-treatment clinical measures (N = 9).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Pre-Treatment Mean (SD)</th>
<th>Post-Treatment Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCL total</td>
<td>49.78 (9.61)</td>
<td>33.78 (16.39) **</td>
</tr>
<tr>
<td>PCL Reexperience mean</td>
<td>2.33 (0.73)</td>
<td>1.47 (0.86) *</td>
</tr>
<tr>
<td>PCL Avoidance mean</td>
<td>2.61 (1.19)</td>
<td>2.06 (1.16)</td>
</tr>
<tr>
<td>PCL Negative Cognitions and Mood mean</td>
<td>2.57 (0.75)</td>
<td>1.79 (0.85) **</td>
</tr>
<tr>
<td>PCL Arousal mean</td>
<td>2.48 (0.45)</td>
<td>1.63 (0.94) *</td>
</tr>
</tbody>
</table>

PCL = PTSD Check List, BDI = Beck Depression Inventory, BAI = Beck Anxiety Inventory, ISI = Insomnia Severity Index, * \( p < 0.05 \), ** \( p < 0.01 \) (paired samples t tests).

4. Discussion

This study demonstrates that live ZNF training among individuals with PTSD is feasible and acceptable. The treatment protocol was executed as planned with few disrup-
tions and participant complaints. Although 25% of participants dropped out of treatment, the dropouts were due to extraneous factors unrelated to treatment, such as the end of the semester and a family emergency. Participants reported high levels of confidence in their ability to perform the in-session tasks as instructed by the research personnel. In addition, overall acceptability ratings were high. Participants provided very high ratings on treatment safety, satisfaction, and willingness to recommend ZNF and moderately high ratings on patient burden and treatment effectiveness.

Preliminary analysis of ZNF’s clinical impact suggests improvements in overall PTSD symptoms. At the symptom cluster level, ZNF showed large effects for Reexperience (Cohen’s $d = 0.81$), Negative Cognitions and Mood (Cohen’s $d = 1.11$), Arousal (Cohen’s $d = 0.91$), and overall PTSD symptomatology (Cohen’s $d = 1.14$), while its effect on avoidance symptoms was not statistically significant (Cohen’s $d = 0.50$). These outcomes are consistent with two previous reports involving 15-session LORETA ZNF training and 24-session NF power training [25,36]. It is noteworthy that considering that typical NF training takes between 30 and 40 sessions to complete, our 10-session ZNF training is time efficient and can significantly reduce patient burden in terms of time and cost.

Once ZNF training was complete, we administered an exit survey to understand how participants perceived its strengths and weaknesses. Participants reported the following strengths: an increased understanding of their mental and bodily states, the pleasant nature of treatment, improvements in cognitive function, and the provision of instant feedback when brain activity deviated from the normal range. They also noted the following weaknesses: hygienic concern about the use of conductance gel and blunt needles, difficulty staying sitting without body movements for an extended period, and time needed to learn to utilize visual feedback for the self-regulation of brain activity. Given such shortcomings, future research may use dry electrodes to address hygienic concerns and shorten the preparation time for EEG recording. Additionally, researchers may consider augmenting an orientation session with a simpler training protocol (e.g., single-channel SMR or alpha training) in order to help participants gain control over their body movements and regulate their brain activity more quickly.

This study has several limitations. First, the single-arm design without a control group limits the interpretation of the significant pre-post changes in PTSD symptoms due to low internal validity and a possible placebo effect. Thus, future research will need to evaluate ZNF in more methodologically rigorous designs, such as randomized controlled trials. Second, the generalizability of study findings is restricted because the study sample was small in size and mainly consisted of college students. Although large effect sizes were observed for the reductions of PTSD-related symptoms, the obtained power ranged from 0.57 to 0.85. To overcome this problem, there is a need for future studies involving large general populations with exposure to diverse trauma types. Third, the treatment duration was relatively short. Although rapid symptom improvements are promising, the dose–response relationship and maintenance, of therapeutic gains must be investigated in future research with follow-ups over extended periods of time. Finally, the current study targeted a large number of EEG parameters involving power, phase, and coherence in four frequency bands and four electrode sites. However, it is possible that not all of these parameters contributed to the observed therapeutic gains. Thus, future research is needed to further explore optimal training targets that closely match the PTSD symptom profiles of each patient.

5. Conclusions

In summary, the results of this study demonstrated that ZNF was feasible, acceptable, and potentially efficacious in reducing PTSD symptoms. The study protocol was executed for all study participants as planned, and none of the participants reported any significant adverse events. Further, acceptability and ratings were high across all domains, including safety and treatment satisfaction, while self-assessment results showed promising results.
for symptom improvement. These findings highlight the need for future treatment outcome studies with larger and more diverse samples and active control groups.

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**Institutional Review Board Statement:** The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of Western Kentucky University (22-158).

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

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**Conflicts of Interest:** The author declares no conflict of interest.

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