

The Effectiveness of Using Neurofeedback in the Treatment of Post-Traumatic Stress Disorder: A Systematic Review

Lisa S. Panisch¹  and Audrey Hang Hai¹

Abstract

Neurofeedback is an innovative treatment for post-traumatic stress disorder (PTSD) that is readily accessible to mental health therapists. As a widespread mental health concern with potentially devastating long-term consequences on psychosocial functioning, PTSD can also adversely impact biophysiological processes, particularly those related to the brain. Neurofeedback has shown promise in alleviating overall PTSD symptoms, including these underlying neurobiological consequences. Successful results have been found among clients with PTSD who have not been responsive to prior treatment modalities. While a strong base of clinical anecdotes and case studies supports its success in treating PTSD, intervention studies on neurofeedback have been critiqued for lack of rigor and poor methodological design. A current systematic review of the literature on the effectiveness of neurofeedback in treating PTSD was conducted. Unlike prior reviews which emphasized neurobiological changes, this study was written for the mental health therapist and focused solely on behavioral outcomes. Ten studies met the criteria for inclusion in this review. Neurofeedback demonstrated salubrious results in at least one outcome measure for the majority of participants across all studies. Interpretations, however, are limited by wide discrepancies in sample sizes, study designs, outcome measures, and the extent of reported results. Future research in this area would benefit from prioritizing randomized controlled trials with larger sample sizes and longitudinal follow-up results.

Keywords

post-traumatic stress disorder, neurofeedback, EEG biofeedback, trauma, dissociation, emotional regulation, neurobiology

Post-traumatic stress disorder (PTSD) is a devastating condition that has a substantially adverse impact on an individual's mental and physical health, productivity, and quality of life (Chopra et al., 2014; Pagotto et al., 2015). PTSD can exacerbate other health conditions and lead to poorer physical health outcomes when compared to those with the same condition who do not have PTSD (Asnaani, Reddy, & Shea, 2014; Irish et al., 2013; Pagotto et al., 2015). According to the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013), consideration of PTSD is warranted when an individual displays symptoms that meet specific diagnostic criteria for more than 6 months following exposure to one or more traumatic events. The DSM-5 states that individuals with PTSD may suffer from symptoms including nightmares, flashbacks, intrusive thoughts, hypervigilance, difficulties with concentration or sleep, dissociative phenomena such as depersonalization and derealization, among others. The estimated lifetime prevalence rate among adults in the United States is 6.8% of the population (Kessler et al., 2005). Among those who have served in the military, the estimated lifetime prevalence in Vietnam veterans is 30.9% in males and 26.9% in females (Kulka et al., 1990). The current prevalence in male and female veterans of the

Gulf War and Operation Enduring Freedom/Operation Iraqi Freedom was estimated to be 10.1% and 13.8%, respectively (Kang, Natelson, Mahan, Lee, & Murphy, 2003; Tanielian & Jaycox, 2008).

The widespread prevalence of the disorder and level of suffering of those who experience it has led to innovative approaches to treatment interventions. To date, the intervention with the strongest evidence base is prolonged exposure therapy (PET; Difede, Olden, & Cukor, 2014). However, some individuals fail to respond to PET and other established trauma treatments. Researchers have raised concern about the effectiveness of PET for complex forms of trauma, such as multiple and repeated trauma stemming from childhood abuse, particularly when beginning at a preverbal age (van der Kolk, 2015). In these cases, it is hypothesized that conventional treatments may

¹ Steve Hicks School of Social Work, University of Texas at Austin, Austin, TX, USA

Corresponding Author:

Lisa S. Panisch, Steve Hicks School of Social Work, University of Texas at Austin, 1925 San Jacinto Blvd., Austin, TX 78712, USA.
 Email: lpansch@utexas.edu

be impeded by the physiological consequences of childhood adversity and/or other forms of complex trauma, such as emotional dysregulation caused by instability of the brain's limbic system and extreme hypervigilance resulting from an over-aroused central nervous system (Askovic, Watters, Aroche, & Harris, 2017; Fisher, 2014; van der Kolk, 2015). In these cases, clinical progress is unlikely to be made unless these physiological issues are addressed. Neurofeedback is an example of an intervention that has shown promise in alleviating such physiological symptoms (Benioudakis et al., 2016; Kadosh, Zich, Lisk, & Lau, 2017; Keynan & Hendler, 2017). Research evaluating the effectiveness of neurofeedback as both a stand-alone and adjunctive treatment for PTSD is currently being conducted.

Neurofeedback is a noninvasive treatment approach that uses neuroimaging technology, such as an electroencephalography (EEG) or functional magnetic resonance imaging (fMRI), in real time to promote an individual's regulation of their own brain activity. During a typical EEG neurofeedback session, electrodes are placed on a client's head that are connected to a computer monitor with EEG software installed. A training protocol is selected, which is a type of treatment that targets the self-regulation of specific amplitudes and/or frequencies of an individual's electrophysiological activity in ways meant to contribute to beneficial clinical changes such as reduced anxiety and aggression or enhanced concentration and focus (Fisher, 2014). The EEG interacts with neurofeedback software to provide real-time feedback to an individual on the state of their brain activity via audio and/or visual stimuli; for example, the software described by Fisher (2014) uses a video game in which an individual's spaceship will go faster than others on the computer screen when the desired training thresholds are met. A comprehensive overview of using EEG neurofeedback in therapeutic practice with clients who have experienced trauma can be found in Fisher (2014). While fMRI neurofeedback utilizes similar training concepts, this type of neurofeedback is rarely used outside of university research environments due to the expense and training burden involved in utilizing this type of equipment. In contrast, EEG neurofeedback can be installed onto desktop and laptop computers and is therefore more easily accessible to clinicians working in community practice settings.

This type of intervention can lead improvements in emotional regulation or an individual's ability to cope with difficult emotions and respond appropriately to the situations that trigger them (Rolston & Lloyd-Richardson, n.d.). Difficulties with emotional regulation is thought to play a salient role in numerous psychiatric conditions (Berking & Wupperman, 2012), including PTSD (Cloitre, Miranda, Stovall-McClough, & Han, 2005). While neurofeedback has demonstrated results as an efficacious evidence-based practice in treating attention deficit hyperactivity disorder (Evans, Owens, & Bunford, 2014; Fox, Tharp, & Fox, 2005), its effectiveness in treating various psychiatric conditions is currently being studied (Begemann, Florisse, van Lutterveld, Kooyman, & Sommer, 2016). There are several existing studies that assess the effectiveness of

neurofeedback as an intervention in the treatment of PTSD (Reiter, Andersen, & Carlsson, 2016), particularly for patients with chronic or intractable symptoms.

The demand for research of this nature has largely been driven by the success reported by mental health therapists in clinical anecdotes and case studies of individuals who failed to respond to other forms of treatment. In a 2016 case study, Fisher, Lanius, and Frewen described the salubrious changes experienced by a woman with complex PTSD related to severe and repeated developmental trauma who was treated with EEG neurofeedback in conjunction with psychotherapy. Of note, the authors reported substantial gains in the woman's ability to regulate her emotions. This increased capacity for emotional regulation allowed the woman, previously regarded as being "untreatable" (Fisher, Lanius, & Frewen, 2016, p. 259), to engage in and benefit from psychotherapy in a manner that had not previously been accessible to her.

Two case studies of individuals with intractable PTSD resulting from torture and refugee experiences were described by Askovic, Watters, Aroche, and Harris (2017). The authors stated that both participants had previously received trauma-focused treatment and/or medication, which had no effect on alleviating their symptoms. Following personalized treatments using EEG neurofeedback as an adjunctive intervention to their existing therapeutic regimes, the participants both demonstrated clinically significant decreases in symptoms of PTSD and in symptoms of anxiety and depression. In addition, both participants showed improvements in terms of their memory, attention, and cognitive control. In congruence with the results of Fisher, Lanius, and Frewen (2016), Askovic and colleagues (2017) asserted that neurofeedback was meant to serve as an adjunctive intervention that allows individuals to benefit from previously unsuccessful therapeutic interventions by regulating the underlying physiological arousal and emotional instability associated with PTSD.

While clinical anecdotes and case studies touting the effectiveness of neurofeedback may be enticing on their own, it is imperative for them to be supported by the results of well-conducted research studies. Despite its reported promise in clinical settings, intervention research in neurofeedback has been criticized for poor methodological designs, small sample sizes, potentially contaminated EEG results, lack of placebo control, and a paucity of randomized control trials (RCTs; Lohr, Meunier, Parker, & Kline, 2001; Niv, 2013; Reiter et al., 2016; Sitaram et al., 2017; Waschbusch & Hill, 2001). It is important for mental health therapists to critically evaluate the research base of evidence when considering which interventions will be most beneficial to use with their clients. This is of particular relevance when considering neurofeedback as either an adjunctive or stand-alone intervention for PTSD, since evidence-based treatments for PTSD, such as PET, have already been established in the research literature.

Systematic reviews can benefit mental health therapists with limited time and monetary resources to spend on multiple journal subscriptions by summarizing major findings of intervention research in one article. To aide mental health therapists an

inquiry of this nature, a systematic review of the literature was conducted to assess the effectiveness of neurofeedback interventions in the treatment of PTSD. This study builds upon previous reviews (e.g., Reiter et al., 2016) by including the results of newly published studies in this area. In addition, prior reviews have emphasized neurophysiological changes, as indicated by complex neuroimaging analytic techniques, in their evaluation of successful treatment. The majority of therapists in clinical mental health settings use measures of behavioral changes as a means of evaluating their practices (Bloom, Fischer, & Orme, 2009). Written for the typical therapist with little formal training in neuroscience, this review focused solely on using behavioral changes indicating a reduction in PTSD symptomology as an outcome. Therapists who are trained to interpret results of neuroimaging data are encouraged to refer to the individual studies listed in this review to obtain this information.

Method

This review considered intervention studies of individuals with PTSD who were being treated with some form of neurofeedback therapy. PTSD was defined by the version of the World Health Organization's International Classification of Diseases (ICD) or the DSM version in use during the time when the study took place. For example, participants in a study that happened in 2010 would be required to meet the criteria for a diagnosis listed in the ICD-10 or the DSM IV-TR, while subjects in a 2016 study would need to meet the diagnostic criteria of the ICD-10 and the DSM-5. Neurofeedback was operationalized as any type of noninvasive biofeedback using some form of real-time neuroimaging technology to train participants in the regulation of their brain functioning.

Following a consultation with a reference librarian at a large, public research university, a systematic search of all articles in PsycINFO, CINAHL Plus, Health Source: Nursing/Academic Edition, MEDLINE, Military & Government Collection, and SocINDEX was conducted between October 15 and October 20, 2017. The following search string was used: ("neurofeedback" OR "EEG biofeedback" OR "neurotherapy") AND ("PTSD" OR "post traumatic stress disorder" OR "posttraumatic stress disorder" OR "post-traumatic stress disorder") AND ("treatment" OR "intervention" OR "therapy"). We included all quantitative intervention studies written in English using primary data that evaluated the effectiveness of neurofeedback in treating PTSD. Preexperimental, quasi-experimental, experimental, and case-controlled designs were included; qualitative and single subject case studies were not. All studies meeting inclusion criteria that were published before October 2017 were included.

To meet inclusion criteria, participants were required to have a diagnosis of PTSD. In order to most accurately reflect the profile of a typical client with PTSD seen by therapists in clinical mental health practice settings, comorbid disorders were not excluded, nor were studies in which participants were taking psychotropic medications. Included participants could be of any age, gender, race, ethnicity, nationality, education

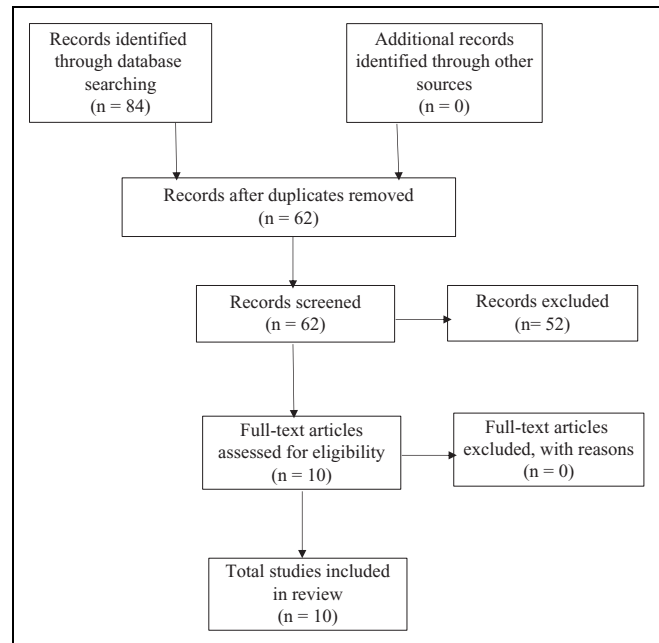


Figure 1. Flow of information from identification to inclusion of studies.

level, or socioeconomic status, and they could be either civilians, on active military duty, or veterans.

All studies using a noninvasive form of neurofeedback intervention were included, regardless of what type of neuroimaging technology (e.g., EEG, fMRI) or training protocol was used. Noninvasive neurofeedback interventions were defined as any type of treatment protocol using neuroimaging technology for the purpose of teaching self-regulation of the brain, without the use of external stimulation. Behavioral change was measured by either validated behavioral assessments and screenings, a participant's self-report, by the reports of informers such as spouses or family members, or by any combination of these.

Results

Our search followed the guidelines set by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses; the search process and results are illustrated by the diagram in Figure 1. Eighty-four articles were initially identified by the search string, with 62 remaining after duplicates were removed. Two coders conducted the initial screening of these articles via titles and abstracts. Any discrepancies in coding were discussed between them, with the condition that a third coder would be brought in to aide in decisions if a mutual decision on any article could not be reached. Fifty-two articles did not meet the inclusion criteria. After coding the full text of the 10 remaining articles (Gapen et al., 2016; Gerin et al., 2016; Kelson, 2013; Kluetsch et al., 2014; Nicholson et al., 2016, 2017; Peniston & Kulkosky, 1991; Peniston, Marrinan, Deming, & Kulkosky, 1993; Smith, 2008; van der Kolk et al., 2016), both coders agreed to include them all in the review. The publication dates of the included studies ranged from 1991 to 2017. A descriptive summary of all studies can be found in Table 1.

Table 1. Study Demographics, Design, Outcome Measures, and Results Summary.

Study	Design and Description	Overall Sample Size	Sample Population	Outcome Measures	Reported Results Summary
Gapen et al. (2016)	Pilot/exploratory, two-group active treatment design, with each group randomly assigned to one of the two different neurofeedback protocols to treat symptoms of post-traumatic stress disorder (PTSD), intervention = 40 sessions of electroencephalography (EEG) neurofeedback lasting 12–21 min each (raised by 3-min increments whenever positive change was reported)	$N = 23$	Adults with PTSD diagnosis, all of whom experienced trauma prior to age 18	Davidson Trauma Scale (DTS), Inventory of Altered Self-Capacities-Affect Dysregulation (IASC), self-report (self-reported checklist of behavioral changes associated with symptoms of over- and under-arousal)	Reductions in overall PTSD scores for the overall sample (from 69.14 to 49.26 on the DTS), with related reductions in affect dysregulation (from 23.63 to 17.20 on the Inventory of Altered Self-Capacities-Affect Dysregulation). No statistically significant differences were found between the two active treatment groups.
Gerin et al. (2016)	Pilot/exploratory, no control group, intervention = three sessions of functional magnetic resonance imaging (fMRI) neurofeedback lasting 30 min each	$N = 3$	Adult male combat veterans with PTSD diagnosis	Clinician-Administered PTSD Scale (CAPS) for DSM-IV-revised, PCL-M for DSM-IV, Beck Depression Inventory (BDI), State-Trait Anxiety Inventory (STAI)	Clinically significant decreases in CAPS scores were found in two of the three participants, a drop in symptom severity from extreme to moderate, and another from moderate to asymptomatic was observed at the conclusion of the study. Clinically significant reductions in BDI and STAI scores were reported for two of the participants, while these scores increased for a third participant.
Kelson (2013)	randomized control trial (RCT), wait-listed control group received no treatment, intervention = 20 sessions of EEG neurofeedback lasting 30 min each	$N = 10$, experimental ($n = 5$), Control ($n = 5$)	Adult male veterans living in poverty (homeless or nearly homeless) with PTSD diagnosis	Self-report using a 23-item Likert-type scale for PTSD symptoms	Compared to the control group, statistically significant postintervention decreases in PTSD symptoms were reported by the experimental group.
Kluetsch et al. (2014)	Pilot/exploratory, no control group, intervention = one session of EEG neurofeedback lasting 36-min	$N = 21$	Adults with PTSD diagnosis related to childhood trauma	Thayer's Activation–Deactivation Adjective Checklist, Spielberger's State Anxiety Inventory	Differences between pre- and postintervention anxiety were not found at the group level, although statistically significant postsession reductions in anxiety levels were reported.
Nicholson et al. (2016)	Pilot/exploratory, no control group, intervention = one session of EEG neurofeedback lasting 36-min	$N = 21$	Adults with PTSD diagnosis related to childhood trauma	CAPS, Multiscale Dissociation Inventory (MDI, averaged scores and MDI depersonalization/derealization averages), Spielberger's State Anxiety Inventory, Thayer's Activation/Deactivation Adjective Checklist, self-report (control over the signal feedback they were receiving, how the experience made them feel, and what strategy they found to be successful)	Postintervention decreases were observed regarding levels of anxiety, arousal, depersonalization/derealization, and overall CAPS scores.

(continued)

Table 1. (continued)

Study	Design and Description	Overall Sample Size	Sample Population	Outcome Measures	Reported Results Summary
Nicholson et al. (2017)	Pilot/exploratory, no control group, intervention = three sessions of fMRI neurofeedback lasting 9 min each, followed by one transfer session without neurofeedback	N = 10	Adults with PTSD diagnosis resulting from childhood trauma	CAPS, Response to Script-Driven Imagery Analysis (RSDI, to assess state changes in PTSD and dissociative symptoms), fMRI scans following the transfer session (to assess whether changes in emotional regulation were sustained)	Participants were reported to have decreases in dissociative symptomology and increased levels of emotional regulation following the intervention, statistically significant changes were not found regarding state PTSD symptoms.
Peniston and Kulkosky (1991)	RCT, control group received treatment as usual, intervention = 30 sessions of neurofeedback lasting 30 min each, in addition to a pretraining phase with 8 sessions of autonomic temperature biofeedback training	N = 29, experimental (n = 15), control (n = 14)	Adult male veterans with PTSD diagnosis	Minnesota Multiphasic Personality Inventory (MMPI)	The experimental group was found to have statistically significantly lower postintervention MMPI scores than the control group.
Peniston, Murrinan, Deming, and Kulkosky (1993)	Pilotexploratory, no control group, intervention = 30 sessions of EEG neurofeedback lasting 30 min each, in addition to a pretraining phase with 5–6 sessions of autonomic temperature biofeedback training	N = 20	Adult male veterans with PTSD diagnosis, experiencing 2–3 weekly incidences of nightmares or flashbacks, comorbid alcohol abuse	Monthly self-reports (whether or not participants continued to experience nightmares or flashbacks) in addition to reports from informers (e.g., a spouse or family member) for a duration of 26 months	Eighty percent of participants no longer experienced flashbacks or nightmares in the 26 months following the intervention.
Smith (2008)	Pilot/exploratory, no control group, intervention = 30 sessions of neurofeedback lasting 30–40 min each	N = 10	Adult male combat veterans with PTSD and comorbid PTSD-induced depression	Hamilton Depression Rating Scale (HAM-D), Test of Variables of Attention (TOVA)	The Man–Whitney <i>U</i> -test showed statistically significant improvements between pretest and posttest on the HAM-D ($U = 100, p < .001$). Statistically significant improvements were found on two of the five components of the TOVA, including variability ($U = 77, p < .05$) and d-prime ($U = 20, p < .05$), but not for omissions, commissions, and response time.
van der Kolk et al. (2016)	RCT, waitlisted control group received treatment as usual, intervention = 24 sessions of neurofeedback lasting 12–30 min each	N = 52, experimental (n = 28), control (n = 24)	Adults with PTSD, all demonstrating no clinical improvement following a 6-month period of trauma-focused treatment	CAPS, DTS, IASC	Clinically significant postintervention improvement in CAPS and IASC scores were found for the experimental group, but not for the control group, with reported within-groups and between-groups effects sizes of $d = -2.33$ and $d = -1.71$, respectively, 70% of participants in the experimental group failed to meet the diagnostic criteria for PTSD following the intervention.

Participants

Sample size. The total sample size across all studies was 178. Two studies utilized data from the same sample of participants (Kluetsch et al., 2014; Nicholson et al., 2016). Thus, to obtain our total sample size, the participants in these studies ($N = 21$) were only counted once. The samples across different studies ranged in size, with the smallest consisting of 3 participants (Gerin et al., 2016), to the largest that had 52 participants (van der Kolk et al., 2016), and was the only study out of the eight reviewed to have more than 30 participants. In the remaining studies, sample sizes of 10 (Kelson 2013; Nicholson et al., 2017; Smith, 2008), 20 (Peniston et al., 1993), 23 (Gapen et al., 2016), and 29 (Peniston & Kulkosky, 1991) were reported.

Demographic characteristics. All the study participants were adults, aged 18 years or older. Five studies included only males in their sample (Gerin et al., 2016; Kelson, 2013; Peniston & Kulkosky, 1991; Peniston et al., 1993; Smith, 2008). The rest of the studies examined both male and female participants. Racial/ethnic characteristics of the participants were only reported in three studies (Gapen et al., 2016; Kelson, 2013; van der Kolk et al., 2016). Of the 46 participants who provided information about their race/ethnicity in van der Kolk et al.'s (2016) RCT, over 75% ($N = 35$) were White, four participants were Black, one was Native American/Alaska Native, and those remaining listed their race/ethnicity as either "multiethnic" ($N = 4$) or "Other" ($N = 2$). Half of the male participants in Kelson's (2013) study were Black ($N = 5$), the other half was comprised of Hispanic ($N = 3$) and White males ($N = 2$). While Gapen and his colleagues (2016) reported that their sample was "primarily White ($N = 19$) and female ($N = 15$)" (p. 252), no further details about race/ethnicity or gender were provided.

Military/veteran status. The five studies with only males ($N = 72$) each assessed the effectiveness of neurofeedback interventions for treating PTSD in military veterans (Gerin et al., 2016; Kelson, 2013; Peniston & Kulkosky, 1991; Peniston et al., 1993; Smith, 2008), while the military status of participants in the remaining studies was either described as being civilian non-veterans or was not reported. In four of the military studies (Gerin et al., 2016; Peniston & Kulkosky, 1991; Peniston et al., 1993; Smith, 2008), the participants were described as having PTSD related to combat. Four of the 10 veterans in Kelson's (2013) study were reported to have combat-related PTSD. In two studies (Peniston & Kulkosky, 1991; Peniston et al., 1993), all the participants ($N = 49$) were veterans of the Vietnam War. Eight of the 10 veterans in Smith's (2008) study had served in Iraq and the remaining two were Vietnam veterans. The three participants in the study by Gerin et al. (2016) were veterans of either Operation Enduring Freedom, Operation Iraqi Freedom, or Operation New Dawn. Information was not provided about which wars the veterans in Kelson's study had served in, if any.

History of childhood trauma. Childhood exposure to trauma was specifically mentioned in the sample of participants analyzed by Kluetsch et al. (2014) and Nicholson et al. (2016), as well as in the participants of studies conducted by Gapen et al. (2016) and Nicholson et al. (2017). Some veterans in Kelson's (2013) study were reported to have experienced family abuse and family trauma, along with trauma related to violence; further information was not provided. Childhood exposure to trauma was not reported in any of the remaining studies, and no additional details on the nature of the participant's traumatic experiences were provided.

Comorbid conditions. Comorbidity with alcohol abuse was reported in one study (Peniston et al., 1993). Ten additional comorbidities of participants in the sample studied by Kluetsch et al. (2014) and Nicholson et al. (2016) were described. In addition to PTSD, participants within this sample met the diagnostic criteria for major depressive disorder ($N = 8$), dysthymic disorder ($N = 1$), panic disorder with agoraphobia ($N = 1$), panic disorder without agoraphobia ($N = 3$), agoraphobia without panic disorder ($N = 2$), social phobia ($N = 3$), somatization disorder ($N = 2$), undifferentiated somatoform disorder ($N = 5$), bulimia nervosa ($N = 1$), and eating disorder not otherwise specified ($N = 1$). All participants in Smith's (2008) study ($N = 10$) had PTSD-induced depression. In Kelson's (2013) study, 9 of the 10 veterans were reported to have suffered at some point in their lives with substance use, and it was reported that "some of the veterans had been diagnosed with bipolar disorder, but by their reporting, this could have been due to drug or alcohol addiction" (p. 89), and further details were not provided. Comorbidities of participants in other studies were not reported.

Design Characteristics

All studies took place in the United States or Canada. Three studies were RCTs (Kelson, 2013; Peniston, & Kulkosky, 1991; van der Kolk et al., 2016). In two of these, the control groups received treatment as usual (Peniston & Kulkosky, 1991; van der Kolk et al., 2016). The control group in the remaining study received no treatment (Kelson, 2013). The control group participants in two studies (Kelson, 2013; van der Kolk et al., 2016) were wait-listed to receive the same neurofeedback intervention as the experimental group after the conclusion of the intervention. No details were provided about the waitlist status of participants in Peniston and Kulkosky's (1991) control group.

The remaining seven articles (Gapen et al., 2016; Gerin et al., 2016; Kluetsch et al., 2014; Nicholson et al., 2016, 2017; Peniston et al., 1993; Smith, 2008) were pilot studies or utilized exploratory designs. In one of these studies (Gapen et al., 2016), a two-group active treatment design was used, with each group randomly assigned to receive one of the two different neurofeedback protocols.

Intervention Characteristics

Neuroimaging technology. In all 10 studies, either EEG, fMRI, or a combination of the two technologies was used, either as part of the neurofeedback itself or as a measure to assess changes related to treatment. In terms of the neurofeedback intervention, EEG technology was used in eight studies (Gapen et al., 2016; Kelson, 2013; Kluetsch et al., 2014; Nicholson et al., 2016; Peniston & Kulkosky, 1991; Peniston et al., 1993; Smith, 2008; van der Kolk et al., 2016). Neurofeedback using fMRI technology was used in two studies (Gerin et al., 2016; Nicholson et al., 2017).

Intervention length, duration, and adjunctive treatments. The length of the interventions used across studies ranged from one 36-min session (Kluetsch et al., 2014; Nicholson et al., 2016) to 40 sessions of 21–26 mins of neurofeedback (Gapen et al., 2016). In other studies, treatment length and duration were reported as three 9-min sessions (Nicholson et al., 2017); three 30-min sessions (Gerin et al., 2016); twenty 30-min sessions (Kelson, 2013); thirty 30-min sessions (Peniston & Kulkosky, 1991; Peniston et al., 1993); 24 sessions, lasting from 12 to 24 min (van der Kolk et al., 2016); and 30 sessions, each lasting from 30 to 40 min (Smith, 2008).

The use of adjunctive treatments was reported in two of the studies (Peniston & Kulkosky, 1991; Peniston et al., 1993). Prior to the neurofeedback interventions in both of these studies, a pretraining phase took place that consisted of either eight (Peniston & Kulkosky, 1991) or six (Peniston et al., 1993) 30-min sessions of temperature biofeedback, in which participants were trained to gain control over their body temperatures, in an effort to produce a state of relaxation at will.

Measures

Standardized measures were used to assess PTSD symptoms in 8 of the 10 studies; the studies by Kelson (2013) and Peniston, Marrinan, Deming, and Kulkosky (1993) did not use standardized measures. Instead, veterans in Kelson's study were assessed by self-reports, via a 23-item Likert-type (1–5 rating) scale measuring PTSD symptoms; no information about the instruments' psychometric properties was reported. Behavioral changes in Peniston et al.'s (1993) study were measured by monthly self-reports of PTSD symptoms in addition to reports from informers (e.g., a spouse or family member). Self-reported outcomes were used in two other studies, in combination with standardized assessments (Gapen et al., 2016; Nicholson et al., 2016).

A wide variety of standardized assessments were used across eight studies. These included the Davidson Trauma Scale (DTS), the Inventory of Altered Self-Capacities (IASC)-Affect Dysregulation, the PTSD Checklist for military (PCL-M) for DSM-IV, the Beck Depression Inventory (BDI), the State-Trait Anxiety Inventory (STAI), the Multiscale Dissociation Inventory (MDI), the Response to Script-Driven Imagery Analysis (RSDI), the Minnesota Multiphasic Personality

Inventory (MMPI), Thayer's Activation–Deactivation Adjective Checklist; Spielberger's State Anxiety Inventory, the Clinician-Administered PTSD Scale (CAPS), the Hamilton Depression Rating Scale (HAM-D), the Test of Variables of Attention (TOVA), and the CAPS for DSM-IV-revised.

The DTS and IASC were both used in the same two studies (Gapen et al., 2016; van der Kolk et al., 2016), as was Thayer's Activation–Deactivation Adjective Checklist and Spielberger's State Anxiety Inventory (Kluetsch et al., 2014, Nicholson et al., 2016). The PCL-M for DSM-IV was used with the veteran participants in Gerin and colleague's (2016) study. Gerin et al. also used the BDI and the STAI. The MDI was used in one study (Nicholson et al., 2016), as was the MMPI (Peniston & Kulkosky, 1991), HAM-D (Smith, 2008), TOVA (Smith, 2008), and RSDI (Nicholson et al., 2017). The CAPS was used in three studies (Nicholson et al., 2016, 2017; van der Kolk et al., 2016), and the CAPS for DSM-IV-revised was used in one study (Gerin et al., 2016).

Reported Outcomes

All studies reported reductions in PTSD symptoms for the majority of participants receiving neurofeedback interventions. Peniston and Kulkosky (1991) reported that statistically significant differences in mean pre- and posttest MMPI scores were found between the intervention and control groups, with the treatment group demonstrating significantly lower scores following the intervention than the control group. While no group-level changes between pre- and postintervention state anxiety were observed by Kluetsch and her colleagues in 2014, their findings demonstrated statistically significant decreases in anxiety levels for participants after the conclusion of the intervention. Results from this same sample reported by Nicholson et al. (2016) showed decreases in levels of arousal, anxiety, depersonalization/derealization, and overall CAPS scores following the intervention. After receiving the intervention described in the 2017 study by Nicholson et al., participants demonstrated increased emotional regulation and decreases in dissociative symptoms. Decreases in scores of the DTS (from 69.14 to 49.26) and the IASC (from 23.63 to 17.20) were reported by Gapen et al. (2016) from the time when participants were given preintervention assessments to a follow-up assessment after the conclusion of the intervention; these decreases in PTSD symptoms and affect dysregulation over time had a medium–large effect size ($d = .69$). No statistically significant differences were found between the two active neurofeedback treatment groups, although decreases in PTSD symptoms and affect dysregulation were reported for both groups. In the self-reported results of Peniston et al.'s (1993) study, only one-fifth of the veterans and their informers reported experiencing one to three experiences of symptomatic reoccurrences. All four of these veterans were provided with seven booster sessions of neurofeedback.

Clinically significant reductions in PTSD symptoms were reported by Gerin et al. (2016) and van der Kolk et al. (2016). Gerin et al.'s results showed clinically significant decreases in

PTSD symptoms for two of the participants, as measured by the CAPS Scale. One of these participants dropped from the range of scores indicating extreme PTSD symptoms to moderate symptoms (from 81 to 47), and the other, who initially presented with a moderate level of PTSD symptoms, fell into the asymptomatic range at the conclusion of the intervention (with a decrease in score from 59 to 12). The third participant demonstrated only a three-point drop in his CAPS score (from 55 to 52) indicating that no clinically significant progress was achieved. The latter participant had a statistically reliable drop in his PCL-M scores (from 42 to 37 points), while the other two participants showed clinically significant decreases in their scores (indicated by 10- to 20-point decreases). Two participants demonstrated decreases in their BDI scores, while a third participant's depression score increased; these results were consistent with those found for the STAI scores.

The Man-Whitney *U*-test used by Smith (2008) showed statistically significant improvements between pre- and post-test on the HAM-D ($U = 100, p < .001$). Statistically significant improvements were found on two of the five components of the TOVA, including variability ($U = 77, p < .05$) and d-prime ($U = 20, p < .05$), but not for omissions, commissions, and response time. Of note, two patients reported titrating off of 50 mg of Zoloft by the conclusion of this study.

In van der Kolk et al.'s (2016) study, participants in the treatment group, but not the control group, demonstrated clinically significant changes in their CAPS scores 1 month after the intervention ended. Statistically significant improvements were also observed in IASC subscales measuring tension reduction activities, affect regulation, identity disturbance, and fears of being abandoned. After the intervention was completed, over 70% of participants in the experimental condition failed to meet the criteria necessary to warrant a PTSD diagnosis. Based on the effect sizes found both within groups ($d = -2.33$) and between groups ($d = -1.71$), the authors concluded that neurofeedback is an intervention comparable to established evidence-based practices for PTSD, including PET and cognitive behavioral therapy. Furthermore, they asserted that neurofeedback, in addition to the aforementioned evidence-based interventions, is more effective in treating PTSD than psychotropic medications.

Summary and Conclusions

Neurofeedback offers promise as an intervention for treating PTSD. The results from all 10 studies reviewed in this article demonstrated salubrious changes in at least one outcome measure of PTSD symptomology for the majority of participants in the samples. However, several factors severely limit the interpretation of these results. First, there were notable discrepancies among the designs used in the different studies. Only three of the included studies were RCTs. The remaining majority of the studies used preexperimental designs, making it difficult to ascertain whether any positive outcomes were due to the neurofeedback intervention or other extraneous variables.

There were also wide variations in sample sizes. Except for only one study (van der Kolk et al., 2016), all sample groups consisted of less than 30 participants. Small sample sizes such as these may increase the chances for violations of statistical assumptions of parametric analysis, when used, to occur, thereby casting doubt on findings that result from studies using such procedures. In addition, few studies provided information about the racial/ethnic characteristics of their participants. As such, it is difficult to ascertain whether the sample of participants was truly representative of the population. Over three-quarters of the participants were White in two of the three studies that did provide this information (Gapen et al., 2016; van der Kolk et al., 2016). It is possible that a trend exists in neurofeedback intervention studies in which minority groups are underrepresented as participants; if so, it would be important to investigate the cause of this and take subsequent steps to remedy it. However, we cannot even begin to assess the extent of this issue with the current absence of this information. Furthermore, none of the studies related to PTSD in veterans included females. Therefore, we cannot speculate as to whether women who experience combat-related PTSD would benefit from neurofeedback as an intervention.

A variety of outcome measures were used to examine PTSD symptomatology, many with a specific focus on different clusters of symptoms, such as emotional regulation or dissociation. One study (Smith, 2008) focused on outcome measures from depression resulting from PTSD as opposed to PTSD-specific symptoms. These results provide potentially valuable information in terms of parsing out the benefits of neurofeedback interventions on specific symptoms of or induced by PTSD. However, only a small amount of such symptoms was focused upon, and these specific symptoms were not consistent across studies, thereby impeding our ability to draw any firm conclusions. Furthermore, there were substantial differences in terms of the amount of information reported in each article regarding the results of the outcome measures. Without a full disclosure of the results, a thorough interpretation is difficult. Another concern is that each study used different treatment protocols, and there was little congruence across studies in terms of treatment duration and postintervention follow-up periods. While some researchers have expounded on the benefits of using treatment protocols that are individualized to each patient (Fisher et al., 2016; Reiter et al., 2016), variety in experimental protocols hinders the ability to generalize the results to larger populations. Finally, the majority of the studies did not use longitudinal designs, which calls the sustainability of beneficial postintervention results into question. Taken as a whole, all of these differences impair our ability to draw conclusions that compare treatment effectiveness across studies in an aggregated fashion.

Despite the limitations of these studies, the beneficial treatment results that were reported are congruent with those of numerous case studies and clinical anecdotes (Askovic et al., 2017; Benioudakis et al., 2016; Fisher et al., 2016; Mills, 2012). In conclusion, we assert that promising results from exploratory and pilot studies justify a clear need for additional

experimental research to be conducted. The rigorous design used in van der Kolk et al.'s (2016) study can serve as a model for future research in this area. Future studies should emulate that of van der Kolk and his colleagues by using larger sample sizes and including a full presentation of the results of all stated outcome measures. Ideally, longitudinal designs will be used to assess the sustainability of postintervention results, and multiple types of outcome measures (e.g., a combination of validated psychometric assessments, participant self-reports, and the reports of informants) should be triangulated to maximize internal validity of the study and the robustness of the findings. If neurofeedback consistently demonstrates results in rigorous experimental designs that are similar to the success of van der Kolk et al.'s, therapists in clinical practice must give strong consideration to using it as an intervention to alleviate the suffering of individuals with PTSD.


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ORCID iD

Lisa S. Panisch  <http://orcid.org/0000-0001-9463-129X>

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Author Biographies

Lisa S. Panisch, MSW, is a doctoral student in the Steve Hicks School of Social Work at the University of Texas at Austin. Her research focuses on trauma, dissociation, and health outcomes, with a specific focus on connections between childhood sexual abuse and women's health issues. She is interested in conducting intervention research for people with histories of child maltreatment.

Audrey Hang Hai, MSW, is a doctoral student in the Steve Hicks School of Social Work at the University of Texas at Austin. Her research focuses on spirituality/religiosity's effect on substance use and spiritual/religious interventions for preventing or treating substance use and misuse. She is committed to bringing the healing power of spirituality/religion to people in need through research.