Inhibitory Control and Alcohol Use History Predict Changes in Posttraumatic Stress Disorder Symptoms

Joseph DeGutis[1, 2, 3, 4], Sam Agnoli[1, 3, 4], Charles E. Gaudet[5, 6], Anna Stumps[1, 3, 4],
Sahra Kim[1, 5], Travis C. Evans[3, 4, 6], Audreyana Jagger-Rickels[3, 4, 6, 8], William Milberg[1, 2, 7],
Regina McGlinchey[1, 2, 7], Catherine B. Fortier[1, 2, 7], and Michael Esterman[3, 4, 6, 8]

[1] Translational Research Center for Traumatic Brain Injury and Stress Disorders, VA Boston Healthcare System,
Boston, Massachusetts, United States
[2] Department of Psychiatry, Harvard Medical School
[3] Boston Attention and Learning Laboratory, VA Boston Healthcare System, Boston, Massachusetts, United States
[4] Neuroimaging Research for Veterans Center, VA Boston Healthcare System, Boston, Massachusetts, United States
[5] Psychology Service, VA Boston Healthcare System, Boston, Massachusetts, United States
[6] Department of Psychiatry, Boston University Chobanian and Avedisian School of Medicine
[7] Geriatric Research, Educational and Clinical Center, VA Boston Healthcare System, Boston, Massachusetts, United States
[8] National Center for PTSD, VA Boston Healthcare System, Boston, Massachusetts, United States

Objective: Posttraumatic stress disorder (PTSD) is associated with significant disability and can become chronic. Predictors of PTSD symptom changes over time, especially in those with a PTSD diagnosis, remain incompletely characterized. *Method:* In the present study, we examined 187 post-9/11 veterans (M_{age} = 32.8 years, 87% male) diagnosed with PTSD who performed two extensive clinical and cognitive evaluations approximately 2 years apart. *Results:* We found that greater PTSD symptom reductions over time were related to lower lifetime drinking history and better baseline inhibitory control ability (Color-Word Inhibition and Inhibition/Switching), though not performance on other executive function tasks. Further, groups with reliably Improved, Worsened, or Chronic PTSD symptoms demonstrated significant differences in baseline inhibitory control and lifetime drinking history, with marked drinking differences starting in the early-to-mid 20s. We also found that PTSD symptom changes showed little-to-no associations with changes in inhibitory control or alcohol consumption. *Conclusions:* Together, these findings suggest that, in those diagnosed with PTSD, inhibitory control and alcohol use history reflect relatively stable risk/resiliency factors predictive of PTSD chronicity.

Key Points
Question: In individuals with a diagnosis of PTSD, are changes in PTSD symptoms over time predicted by baseline inhibitory control and cognitive performance as well as current/lifetime alcohol consumption and other clinical variables? *Findings:* Lower lifetime drinking history and better baseline inhibitory control are associated with greater PTSD symptom improvements across 2 years. *Importance:* Inhibitory control and lifetime drinking history represent contributing mechanisms in the chronicity of PTSD symptoms and provide targets for interventions. *Next Steps:* Future research should more comprehensively characterize inhibitory control (e.g., response inhibition, memory suppression, using nonemotional and emotional or trauma-related material) to understand what best predicts PTSD symptom changes as well as examine the effectiveness of cognitive and pharmacological approaches to improving inhibitory control.

Posttraumatic stress disorder (PTSD) is associated with heterogeneous symptom trajectories, and the identification of reliable factors predicting changes in PTSD symptoms has been elusive (Bonanno, 2004; Bonanno & Mancini, 2012; Karstoft et al., 2015; Lee, Bryan, et al., 2020; Sripada et al., 2017). In veteran populations, PTSD is often chronic, sometimes spanning decades (Lee, Lee, et al., 2020; Marmar et al., 2015). Identifying factors that predict PTSD chronicity represents an important target for potential interventions. Alcohol use and cognitive dysfunction, specifically inhibitory control deficits, have shown some preliminary relationships with the chronicity of PTSD symptoms and PTSD treatment outcomes (Aupperle et al., 2012; Crocker et al., 2018; Tripp et al., 2020). However, research has yet to examine the specificity of these relationships, or whether other comorbidities are related to changes in PTSD symptoms, which was the goal of the present study.

Preexisting and posttrauma vulnerabilities related to PTSD symptom *development* have been relatively well studied (e.g., Elwood et al., 2009; Marx et al., 2009; Samuelson et al., 2020; Schultebraucks et al., 2022; see Pavlacic et al., 2022, for a recent review). For example, Galatzer-Levy et al. (2017) found that, in trauma-exposed adults, the presence of childhood trauma was related to the development of PTSD 5 months later. Other studies have implicated cognitive abilities in the development of PTSD. For example, in U.S. soldiers, poorer predeployment sustained attention and inhibitory control predicted worse postdeployment PTSD symptoms (Samuelson et al., 2020). Further, poorer cognitive performance across a broad battery (e.g., processing speed, memory, inhibitory control) 1 month after trauma exposure (Schultebraucks et al., 2022) as well as worse self-reported executive functioning (EF) after trauma exposure (Bardeen et al., 2022) have been shown to predict the development and severity of PTSD.

Though these studies provide insights into the predictors of PTSD development in the months and years after trauma exposure, risk factors for developing PTSD often do not predict the more long-term time course of those with a PTSD diagnosis (Brewin, 2005; Friedman et al., 1994). A better characterization of predictors of symptom changes in a real-world sample diagnosed with PTSD (as opposed to those enrolled in a clinical trial) could help identify individuals who need additional services and provide novel targets for treatment. Sripada et al. (2017) took a step toward this goal and examined the predictors of symptom changes over 3 months in a sample of 2,237 veterans with PTSD. They found that chronic/worsening PTSD symptoms over 3 months were related to being male, non-White, and having baseline depression and sleep disorders. Lee, Lee, et al. (2020) recently examined the 20-year time course of PTSD symptoms in a group of 1,353 post-9/11 veterans assessed at four time points, where 75% had a probable PTSD diagnosis. They found that the strongest predictors of a poorer PTSD symptom time course were depression, suicidal ideation, and current alcohol abuse. The present study endeavored to build on these studies by examining PTSD changes in veterans with a diagnosis of PTSD over a 2-year period and by performing a deeper characterization of potential predictors of PTSD symptom changes, including clinical measures, current and lifetime drinking history (LDH), and performance across a broad battery of cognitive assessments.

Inhibitory Control, Alcohol Use, and the Chronicity of PTSD

Two candidate mechanisms for the maintenance of PTSD symptoms are inhibitory control (Crocker et al., 2018; DeGutis et al., 2015; Samuelson et al., 2020) and alcohol use (Fortier et al., 2021; Holzman et al., 2017; Jacobsen et al., 2001; Norman et al., 2012). Inhibitory control is a core executive function defined as the ability to control one's attention, behavior, thoughts, and/or emotions to override a strong internal predisposition or external lure (Diamond, 2013). Poorer inhibitory control is a risk factor for developing PTSD (Samuelson et al., 2020), and conversely, PTSD may also cause external (trauma-related stimuli) and internal distractors (ruminations, trauma-related thoughts) to become more salient, which could result in poorer inhibitory control performance (Aupperle et al., 2012). Inhibitory control processes may help to regulate decision making, responses to distressing emotions, and other PTSD symptoms, thereby improving functioning and relieving distress in those with better inhibitory control abilities while maintaining PTSD symptoms in those with inhibitory control deficits (Sadeh et al., 2015). Inhibitory control deficits have also been closely associated with alcohol use disorders (AUD; Fortier et al., 2008, 2018; Koob & Volkow, 2010; Noël et al., 2013), both as a risk factor (Wilcox et al., 2014) and as a consequence of alcohol's disinhibiting effects (Rose & Duka, 2008). There is an ongoing debate about whether inhibitory control (e.g., DeGutis et al., 2015) versus general executive functioning (e.g., Aupperle et al., 2012) is mechanistically more important to PTSD development and chronicity, which the present study sought to address.

Alcohol use may also be an important mechanism in the maintenance of PTSD symptoms. AUD is highly prevalent in those with PTSD, with an estimated comorbidity of 30%–50% (Hawn et al., 2020). One prominent framework, the "self-medication" model, suggests that individuals engage in problematic alcohol use to cope with or avoid negative internal experiences related to PTSD (Khantzian, 1997). According to this model, alcohol use could be associated with worse PTSD outcomes because it reflects greater

Correspondence concerning this article should be addressed to Joseph DeGutis, Department of Psychiatry, Harvard Medical School, 150 South Huntington Avenue, Boston, MA 02130, United States. Email: degutis@wjh.harvard.edu

avoidance-coping in general, which has shown to be a strong predictor of a worse symptom trajectory (Badour et al., 2012; Pineles et al., 2011). In contrast, the "mutual maintenance" model suggests more direct interactions between PTSD symptoms and alcohol use, such that increases in alcohol use worsen PTSD symptoms, which in turn can lead to more alcohol use (Simpson et al., 2014). Both models have support in the literature. For example, though baseline alcohol use has been associated with PTSD symptom severity (Kaysen et al., 2006), multiple studies have found little-to-no association between continued alcohol use and *worsening* PTSD symptoms (Kaysen et al., 2011; Langdon et al., 2016), supporting the self-medication model. However, in a study following a marine deployment cycle, greater postdeployment alcohol use was associated with worsening PTSD symptoms after each subsequent time point 1-, 5-, and 8-months postdeployment, supporting the mutual maintenance model (Berke et al., 2019; see also Lee, Lee, et al., 2020; Nickerson et al., 2014; Noël et al., 2013). In assessing support for these models, many of the previous studies are limited in that they analyzed alcohol use categorically rather than continuously (e.g., presence/absence of AUD; Kaysen et al., 2006; Lee, Lee, et al., 2020; McFarlane et al., 2009; Zatzick et al., 2002, 2006), while others failed to account for lifetime alcohol use (Berke et al., 2019; Langdon et al., 2016; Lee, Lee, et al., 2020; McFarlane et al., 2009; Zatzick et al., 2002, 2006). Also, most studies either examined PTSD symptom changes in samples where only a small proportion of participants had a PTSD diagnosis (Berke et al., 2019; Kaysen et al., 2006; Nickerson et al., 2014) or did not assess for PTSD diagnosis (Langdon et al., 2016; Lee, Lee, et al., 2020). A more comprehensive examination of the effects of alcohol use on PTSD changes over time in a sample diagnosed with PTSD could better clarify the role of current and previous alcohol use in maintaining PTSD.

Another important way that alcohol use and inhibitory control may contribute to the chronicity of PTSD is by affecting responses to treatment. Greater baseline and lifetime alcohol use have been associated with increased PTSD treatment dropout (Bedard-Gilligan et al., 2018; Zandberg et al., 2016), and comorbid AUD was associated with poorer treatment response after prolonged exposure therapy (Zang et al., 2019). A recent study assessing the effect of a 12-month prolonged exposure protocol reported that higher levels of alcohol use from each preceding assessment were associated with less PTSD symptom improvements on the following assessment (Tripp et al., 2020). In terms of the relationship between cognitive abilities and PTSD treatment response, poorer pretreatment color-word inhibition, inhibition/switching, and working memory performance have been shown to predict smaller reductions in PTSD symptoms following cognitive processing therapy (CPT) for PTSD (Crocker et al., 2018), whereas in another study of trauma-focused therapy, poorer pretreatment learning/memory predicted reduced PTSD improvements (Haaland et al., 2016). Notably, Crocker et al. (2018) also found that following an executive function training program, individuals with worse inhibitory control and working memory improved their performance and benefited more from CPT.

Taken together, these studies suggest that alcohol use and inhibitory control contribute to the chronicity of PTSD and to the effectiveness of PTSD treatments. The present study sought to extend the current literature in three important ways. First, beyond treatment studies, only a few studies have examined the predictors of PTSD symptom changes over time (e.g., Karstoft et al., 2015; Lee, Lee, et al., 2020), and even fewer have studied symptom changes in individuals with a PTSD diagnosis (e.g., Sripada et al., 2017), where PTSD symptom changes are most relevant. Second, though inhibitory control and alcohol use have been implicated in the time course and chronicity of PTSD symptoms, the specificity of their relationship from other cognitive and clinical measures and each other has not been thoroughly tested. The present study collected a comprehensive clinical and cognitive battery to better characterize this specificity. Finally, we extended previous studies through more rigorously quantifying PTSD symptom changes by combining continuous measures of PTSD change with a reliable change group-based approach and factoring in regression to the mean effects, which have routinely been not taken into account in previous studies.

The Present Study

We recruited a sample of 187 post-9/11 combat veterans with a diagnosis of PTSD and assessed cognitive performance, alcohol use, and other clinical variables (including depression, sleep, and pain) at baseline and follow-up approximately 2 years later. To test the hypothesis that baseline inhibitory control abilities specifically predict PTSD symptom changes over time, we compared validated measures of inhibitory control (Delis-Kaplan Executive Function System [D-KEFS] Color-Word Interference Test, i.e., Stroop) to other executive functions beyond inhibitory control as well as measures of verbal learning and memory. To better understand the role of alcohol use, we assessed continuous measures of current and lifetime alcohol use in predicting changes in PTSD symptoms. Finally, we examined PTSD changes by applying a reliable change approach, accounting for effects of regression to the mean. For converging evidence, we also compared separate groups with significantly improving, chronic, or worsening PTSD symptoms.

Method

Participants

Participants were drawn from a pool of 345 post-9/11 combat deployed veterans recruited into the Translational Research Center for Traumatic Brain Injury (TBI) and Stress Disorders (TRACTS; for a more in-depth description of the sample and methods, see McGlinchey et al., 2017) who participated in data collection at baseline and follow-up visits between the years 2010 and 2019. Participants were recruited from the greater Boston metropolitan area and throughout New England via a full-time recruitment specialist who attended Yellow Ribbon Events, Task Force Meetings, and other events involving U.S. veterans. In the process of recruitment, it was made clear to potential volunteers that our study focuses on understanding TBI, blast exposure, and mental health issues as the result of military service. The term baseline indicates participants' first testing session. However, it is important to note that we do not have assessments from either before deployment or before participants developed PTSD (see the Limitations section for further discussion on this). The TRACTS exclusionary criteria included participants who had a history of neurological/physical impairments ($n = 4$), moderate to severe TBI ($n = 1$), or psychotic disorders ($n = 6$), including bipolar disorder and/or suicidal/homicidal ideation requiring crisis intervention at either assessment. As this study aimed to examine PTSD symptom changes in

those diagnosed with PTSD, a group where PTSD symptom change is most relevant, we focused on individuals with a baseline PTSD diagnosis ($n = 206$, though see Supplemental Materials for analyses of individuals without a PTSD diagnosis). Eighteen additional participants were removed due to evidence of reduced effort on the Medical Symptom Validity Test (see below) at either time point. One participant was removed due to missing data on the primary measure of PTSD symptom severity at follow-up. This left a final sample of 187 participants (see Table 1). The VA Boston Healthcare System institutional review board approved this study, written consent was obtained from all participants, and research was conducted in accordance with the Declaration of Helsinki.

Clinical and Alcohol Use Measures

Clinical Measures

During each assessment session, PTSD diagnosis and severity were assessed using the Clinician-Administered PTSD Scale for the *Diagnostic and Statistical Manual of Mental Disorders, fourth edition* (CAPS-IV; Blake et al., 1995). The CAPS-IV has shown to have excellent reliability (test–retest reliability of .89; Weathers et al., 2001). For mood, anxiety, and alcohol use, we also obtained additional continuous measures (e.g., Depression Anxiety and Stress Scale; Henry & Crawford, 2005; Lovibond & Lovibond, 1995) and diagnostic measures from the Structured Clinical Interview for *Diagnostic and Statistical Manual of Mental Disorders, fourth edition*. Pain was assessed using the McGill Pain Questionnaire (Melzack, 1975), and sleep was assessed using the Pittsburgh Sleep Quality Index (Buysse et al., 1989). TBI was assessed using the Boston Assessment of TBI–Lifetime and diagnosis of a mild/moderate/severe TBI was performed using the Department of Defense consensus criteria for TBI severity as defined in the Clinical Practice Guidelines: Management of Concussion—Mild TBI (Fortier et al., 2014). Clinical measures were highly correlated with each other (see Supplemental Table S1), consistent with previous studies (e.g., Riley et al., 2019).

Table 1
Baseline Characteristics and Demographics of Post-9/11 Veteran Sample

Demographics	Means/percentages
Sample size	187
Gender (M:F)	163:24
Age at baseline (years)	32.79 (8.78)
Education (years)	13.80 (1.82)
Race	
Black	7%
White	76%
Other	17%
Estimated premorbid intelligence (WTAR)	103 (11)
Time since baseline (days)	767 (370)
Military mTBI (%)	57%
Lifetime mTBI (%)	74%

Note. Group means are reported with standard deviation in parentheses. mTBI = mild traumatic brain injury; WTAR = Wechsler Test of Adult Reading.

Alcohol Use

The LDH (Skinner & Sheu (1982) was administered to provide an estimate of current drinking behavior (average and max drinks on a drinking day) and total lifetime alcohol consumption. Total lifetime consumption was adjusted for weight and was also log-transformed due to its nonnormal distribution (see Supplemental Figure S1). This retrospective semistructured interview assesses drinking patterns across the lifespan based on drinking frequency, average number of drinks on drinking days, and maximum number of drinks for each drinking phase. The first drinking phase was defined as the earliest age at which at least one alcoholic drink per month was consumed regularly. In accordance with LDH standardized administration guidelines, each subsequent phase was characterized by a clinically meaningful change in frequency and/or quantity of drinking. Phase-based drinking analyses of the LDH have previously been used in veteran populations, offering a more nuanced look at drinking history prior, during, and after deployment (Jacob et al., 2013). We focused our follow-up analyses on the first three drinking phases since >80% of participants had these three phases. Additional related drinking variables, such as continuous measures of current drinking (maximum and average drinks on a drinking day) and National Institute on Alcohol Abuse and Alcoholism criteria for binge drinking status (National Institute on Alcohol Abuse and Alcoholism, 2015; males: ≥5 drinks/day and ≥1 drinking day/month; females: ≥4 drinks/day and ≥1 drinking day/month), were quantified from the LDH to provide a comprehensive assessment of drinking behaviors.

Cognitive Measures

Performance Validity and Premorbid Functioning

To assess whether effort was sufficient to produce valid test scores, participants were administered the verbal Medical Symptom Validity Test (Green, 2004), similar to our previous studies (e.g., Riley et al., 2019). Per administration guidelines, participants who were below the cut scores defined by the testing manual were excluded ($n = 18$). Premorbid intelligence quotient was estimated using the Wechsler Test of Adult Reading (WTAR; Wechsler, 2001).

Executive Functions: Inhibitory Control

We focused on measures of inhibitory control from the D-KEFS Color-Word Interference Test (CWI, i.e., Stroop Test). The CWI Test involves quickly and accurately reporting the color of a word (e.g., green) while ignoring interference caused by the mismatched name of the word (e.g., blue). It involves both distractor suppression and response inhibition aspects of inhibitory control. The CWI Inhibition/Switching task is similar to the standard CWI Inhibition, but participants must switch between reading the word (an automatic response) and inhibiting the word reading to identify the color of the word. We included both CWI Inhibition and CWI Inhibition/Switching measures, since they measure slightly different aspects of inhibitory control, with Inhibition/Switching having greater inhibitory demands (Bohnen et al., 1992; Delis et al., 2001). The two inhibition measures were standardized, *z*-scored, and averaged into a composite inhibitory control score which was used in the following analyses instead of the individual conditions to increase reliability and decrease Type I errors. We also report the results of CWI Inhibition and Inhibition/Switching scores separately in the

Supplemental Materials, which were very similar to the CWI composite score results. Though it may be suggested that CWI Inhibition/Switching measures task-switching, unlike typical task-switching paradigms the participant switches between an automatic and controlled version of the same task. Further, CWI Inhibition/Switching better correlated with Color-Word Inhibition ($r = .58$, $p < .001$) than task-switching tasks, Trail Making Test Number/Letter Switching subtest ($r = .33$, $p < .001$; Delis et al., 2001), or the Cambridge Neuropsychological Test Automated Battery (CANTAB) Intra–Extra Dimensional Set Shift Task (IED; $r = -.11$, $p = .168$; http://www.cantab.com).

Executive Functions: Domains Beyond Inhibitory Control

Our remaining executive function battery included the following measures: D-KEFS Trail Making Test Number/Letter Switching subtest, that is, Trails B, as a measure of working memory/switching (Delis et al., 2001), D-KEFS verbal fluency (including letter and category switching subtests; Delis et al., 2001), CANTAB IED (number of stages completed) as a measure of task-switching (http://www.cantab.com), and Auditory Consonant Trigrams as a measure of working memory (ACT; Shura et al., 2016). The ACT was not administered to all participants at follow-up; therefore, within-group changes were not examined with this measure. All cognitive measures were age-adjusted z scores except for the IED, where scaled scores were not provided and z scores of the total stages were used. To create a composite measure of executive functions not including inhibitory control, z scores across all measures were averaged.

Verbal Learning and Memory

We measured verbal learning and memory using the California Verbal Learning Test–Second Edition (CVLT-II; Woods et al., 2006). We created a verbal memory composite score consisting of the mean age-adjusted z scores of total learning, short-delay free recall, long-delay free recall, and long-delay recognition hits (see Riley et al., 2019).

Measuring Changes in PTSD Symptoms

We examined change in PTSD symptoms across time points both continuously and categorically. To isolate continuous changes over time that were not attributable to regression to the mean, we computed a continuous, regression-based reliable change metric (i.e., the reliable change index [RCI], standardized regression-based [SRB] model, RCI_{SRB}, McSweeny et al., 1993), as it adjusts for baseline performance, test–retest reliability, and inequality of variance, using the following formula: $\frac{X}{\sqrt{2*(std(T1CAPS)*\sqrt{(1-R)})^2}}$ (Hinton-Bayre, 2016). In this formula, X represents PTSD symptoms at follow-up (Time 2 CAPS) adjusted for baseline PTSD symptoms (Time 1 CAPS), and R is the test–retest reliability of the CAPS-IV (.89, Weathers et al., 2001). Next, to identify groups of individuals that demonstrated a significant change in PTSD symptomatology, we used statistically significant change, $|RCI_{SRB}| > 1.96$, falling outside the 95% confidence interval. We also used a one-tailed cutoff of $|z| = 1.645$, which showed a very similar pattern of results as 1.96 (see Supplemental Tables S7 and S8). Using the 1.96 cutoff, we identified significant individual-level reductions in PTSD symptoms in 21 veterans (Improved PTSD), worsening PTSD symptoms in 28 (Worsened PTSD), and 138 with consistent PTSD symptoms (chronic PTSD, no statistically significant reliable change). Our grouping approach ensured that group membership was not driven by regression to the mean, an issue that often plagues PTSD longitudinal studies (e.g., Kamphuis et al., 2021).

Clinical, Functional, and Cognitive Changes Across Time

Before examining predictors of change over time, we first sought to characterize which clinical, functional, and cognitive measures significantly changed from baseline to follow-up at the group level (paired t tests, ordinal ANOVAs, and McNemar's χ^2 tests). These were exploratory, descriptive analyses and were false-discovery rate (FDR)-corrected for multiple comparisons at .05.

Baseline Predictors of Continuous PTSD Symptom Changes and Symptom Change Groups

The main goal of this study was to identify baseline predictors of changes in PTSD symptoms over time in post-9/11 veterans with a baseline PTSD diagnosis. We examined hypothesized associations of the continuous reliable change in CAPS-IV (RCI_{SRB}) with measures of alcohol consumption and inhibitory control. For alcohol consumption, we separately analyzed current (both average and max drinks on a drinking day) and lifetime consumption (LDH total weight corrected, log transformed), since they may show dissociable effects (e.g., Gmel et al., 2000). For inhibitory control, to reduce Type I errors, we focused on the z-score averaged composite of CWI Inhibition and Inhibition/Switching. Because alcohol use and inhibitory control were our hypothesized measures of interest, we did not FDR-correct these measures. FDR-correction at .05 was applied across all demographic, clinical, and cognitive variables by groups of analyses, that is, once for continuous analyses and once for categorical analyses.

To examine if effects were specific to inhibitory control, we also performed analyses on a composite measure of the executive function measures not including inhibitory control as well as with the verbal memory composite measure (see Riley et al., 2019). Finally, as a further measure of the task specificity of cognitive measures predicting PTSD symptom changes, we ran both forward and backward stepwise regression models predicting the RCI_{SRB}, including all the executive function measures as potential predictors (e.g., Trails Number/Letter Switching, FAS-Letter Fluency). We took a data-driven approach here as an exploratory complement to the theoretical approach used throughout the study. To determine if any additional baseline demographic or clinical variables predicted PTSD symptom changes, we also correlated these baseline measures with RCI_{SRB} (or performed unpaired t tests/analyses of variance [ANOVAs] for categorical variables). Because these analyses were exploratory, we performed FDR-correction at 0.05.

In addition to examining predictors of continuous RCI_{SRB}, for converging evidence, we applied a categorical approach comparing groups with Improved PTSD, Worsened PTSD, and Chronic PTSD using χ^2 tests and one-way ordinal ANOVAs. Similar to the continuous RCI_{SRB} analyses, we focused on the hypothesized domains of current and lifetime alcohol consumption, inhibitory control, and executive functions beyond inhibitory control. We also performed exploratory group comparisons of demographics and other clinical variables, FDR-corrected at 0.05.

Differences in Treatment Engagement Among PTSD Change Groups

We sought to assess between-group differences (χ^2 tests) in treatment participation between baseline and follow-up to determine if differences in PTSD symptom changes could be explained by treatment participation. Treatment was defined as psychotropic medication (e.g., selective serotonin reuptake inhibitors) management with at least one prescription refill and/or evidence of psychotherapy sessions (e.g., CPT, cognitive behavioral therapy, prolonged exposure, marital counseling, acceptance and commitment therapy, eye movement desensitization and reprocessing, group reeducation therapy) in either inpatient or outpatient settings at Veterans Affairs Hospitals, Vet Centers, or private practices. Alcoholics Anonymous (AA) meetings were excluded, as AA meetings do not directly treat PTSD. Treatment (psychotherapy and medication management) was assessed based on participants' reports during an open-ended clinician-administered treatment interview at follow-up. In addition, psychotropic medication management was further assessed using participants' Veterans Affairs medical records dated after the baseline assessment. Treatment participation was coded dichotomously, indicating the presence or absence of any treatment between baseline and follow-up.

In addition, we further parsed treatment participation based on treatment type, as significant differences in the increased efficacy of psychotherapy, compared to medication management, have been reported (Zoellner et al., 2019). Therefore, we coded three additional dichotomous treatment variables that reflect the presence or absence of psychotherapy only, medication management only, or combined treatment (psychotherapy and medication management). We looked at a subset of our sample where the chronic group additionally displayed clinically meaningful stability (±10 points or less on the CAPS-IV; Schnurr & Lunney, 2016). Details regarding these additional analyses and results are reported in Supplemental Table S4.

Associations Between PTSD Changes With Changes in Inhibitory Control and Alcohol Use

Last, we sought to determine if changes in PTSD symptoms were associated with significant changes in inhibitory control and alcohol use (or other clinical variables) and determine if the Improved/ Chronic/Worsened PTSD groups differed in their changes. We ran correlations between change scores (Time 2 residuals after controlling for Time 1) and compared changes in Improved, Chronic, and Worsened PTSD groups.

Transparency and Openness

Raw data files are available following standard data-sharing protocols at the VA Boston Healthcare System (please contact the corresponding author). Computer syntax is available through SPSS and R at request. The study design and analysis plan were not preregistered.

Sample Size Justification

The present study is part of the ongoing TRACTS longitudinal study and has previously found significant cross-sectional associations between PTSD symptoms and both alcohol use (Maksimovskiy et al., 2014) and inhibitory control (Esterman et al., 2019). Previous studies have found significant associations between better baseline inhibitory control and a decrease in PTSD symptoms after treatment (e.g., Haaland et al., 2016; $N = 42$; Crocker et al., 2018, $N = 74$) as well as decreased alcohol use and decreased PTSD (e.g., Lee, Lee, et al., 2020, $N = 1,353$). Relevant to the current investigation, a previous treatment study relating the CWI Inhibition and Inhibition/ Switching tasks to PTSD symptom change over time (Crocker et al., 2018) found effect sizes of $r = 0.29$. Thus, with $\alpha = .05$ and $1-\beta = .80$, it should only require 69 participants to adequately detect these associations. Similarly, while no studies to our knowledge have compared LDH to PTSD symptom change, previous studies relating current alcohol use to PTSD symptom change from Time 1 to Time 2 (Lee, Lee, et al., 2020) found an effect size of $r = .19$ and would require 167 participants. Thus, our current sample size of 187 participants should provide adequate power to detect inhibitory control and alcohol use associations with PTSD changes.

Results

Clinical, Functional, and Cognitive Changes Over Time

Across the entire sample ($N = 187$), most clinical, functional, and cognitive variables remained stable at the group level when comparing baseline and follow-up assessments, with some notable exceptions (see Supplemental Materials, Tables S2 and S3). First, we observed overall significant reductions in PTSD symptoms; CAPS, *baseline*: $M = 68.19$, $SD = 18.72$; *follow-up*: $M = 59.67$, $SD = 25.15$, $t(186) = 5.36$, $q < .001$, as well as reduced alcohol consumption; drinks on a drinking day, *baseline*: $M = 6.96$, $SD = 4.31$; *follow-up*: $M = 6.66$, $SD = 4.45$, $t(184) = 2.35$, $p = .02$; max drinks, *baseline*: $M = 11.93$, $SD = 7.17$; *follow-up*: $M = 11.41$, $SD = 7.01$, $t(184) = 2.53$, $p = .014$. Unsurprisingly, we found that the Improved PTSD group showed significant PTSD symptom improvement, with an average symptom reduction on the CAPS-IV of 43.91, and 19 of these 21 individuals no longer me diagnostic criteria for PTSD at follow-up. The Worsened PTSD group showed significantly increased PTSD symptoms, with an average symptom increase of 23.43.

With regard to cognitive performance (Supplemental Table S3), we found significant improvements in composite inhibitory control, *baseline*: $M = 0.05$, $SD = 0.79$; *follow-up*: $M = 0.28$, $SD = 0.81$, $t(163) = 5.41$, $p < .001$. The only other significant changes in the cognitive battery were worsening performance on the FAS category switching, *baseline*: $M = .50$, $SD = 1.05$; *follow-up*: $M = .23$, $SD = 1.24$, $t(176) = 2.99$, $p = .003$, $q = .032$.

Associations Between Baseline Demographic and Clinical Variables With PTSD Symptom Changes

In our characterization of baseline variables predicting PTSD changes over time, before examining our measures of interest, we first sought to examine demographic and clinical variables predicting PTSD changes. As can be seen in Table 2, correlations between demographic/clinical variables with PTSD symptoms changes (RCI$_{SRB}$) failed to reach significance. Likewise, when examining groups with Improved, Chronic, or Worsened PTSD symptoms, we found no significant group differences (see Table 2).

Table 2

Associations Between Baseline Demographic and Clinical Measures and PTSD Symptom Changes Over Time

Domain	Measure	PTSD+			Worsened PTSD	Chronic PTSD	Improved PTSD	p	q	Range
		r	p	q						
Alcohol use	Lifetime alcohol consumption (weight-adjusted and log-corrected; LDH)	*0.24*	*.001**	—	*7.69 ± 1.40*	*7.19 ± 1.23*	*6.69 ± 1.97*	*.010**	—	0–[11]
	Average drinks on a drinking day (LDH)	0.11	.144	—	8.18 ± 5.32	6.82 ± 3.59	6.24 ± 6.56	.102	—	0–[32]
	Max drinks on a drinking day	0.07	.320	—	*14.33 ± 8.14*	*11.72 ± 6.77*	*10.08 ± 7.85*	*.033**	—	0–[35]
	Current alcohol use disorder (%)	0.10	.164	—	17.86%	20.00%	0.00%	.150	—	—
Demographics	N				28	138	21			
	Gender identity (M:F)	0.02	.742	1.000	25:3	120:18	18:3	.702	0.955	—
	Age	0.14	.057	1.000	33.71 ± 9.00	32.43 ± 8.46	33.86 ± 10.67	.955	1.000	[20–64]
	Race	—	.370**	1.000						—
	Black				10.71%	7.00%	4.76%	.397	0.899	—
	White				67.86%	77.00%	80.95%	.269	1.000	—
	Other				21.43%	16.00%	14.29%	.247	1.000	—
	Education	0.03	.722	0.970	13.21 ± 1.64	13.94 ± 1.87	13.67 ± 1.77	.285	1.000	[12–20]
	Estimated premorbid intelligence (WTAR)	−0.02	.831	0.974	99.86 ± 12.44	104.42 ± 10.90	102.33 ± 11.29	.325	1.000	70–130
	Time since baseline (years)	0.01	.928	1.000	2.25 ± 0.96	2.08 ± 1.06	2.05 ± 0.73	.463	0.984	[.83–7.40]
Clinical measures	PTSD severity (CAPS-IV)	−0.02	.781	1.000	64.82 ± 18.76	69.12 ± 18.73	66.57 ± 18.88	.645	1.000	0–136
	Current mood disorder (%)	0.11	.127	0.993	39.29%	45.65%	33.33%	.781	0.984	—
	Current anxiety disorder (%)	0.02	.804	1.000	28.57%	23.19%	23.81%	.661	1.000	—
	DASS depression	0.10	.204	1.000	13.28 ± 8.73	13.15 ± 10.57	11.05 ± 9.75	.486	0.918	0–42
	DASS anxiety	0.05	.539	1.000	8.76 ± 7.17	9.92 ± 8.18	8.67 ± 9.15	.678	1.000	0–42
	DASS stress	0.02	.786	1.000	15.76 ± 7.49	18.09 ± 9.97	16.00 ± 9.32	.853	0.967	0–42
	Antidepressant (%)	0.05	.530	1.000	33.33%	40.00%	42.86%	.487	0.872	—
	Combat exposure	−0.11	.134	0.938	16.80 ± 10.01	18.47 ± 9.97	19.33 ± 13.31	.472	0.944	0–85
	Military mTBI (%)	−0.06	.432	1.000	53.57%	58.69%	52.38%	.999	0.999	—
	Lifetime mTBI (%)	−0.07	.325	1.000	67.86%	73.19%	85.71%	.177	1.000	—
	Average pain (MPQ)	−0.02	.792	1.000	29.68 ± 20.95	38.05 ± 25.27	37.76 ± 25.11	.277	1.000	0–78
	Overall sleep quality (PSQI)	0.00	.983	0.983	11.92 ± 3.58	11.95 ± 4.14	11.95 ± 3.92	.977	1.000	0–21
	Overall daily life functioning (WHODAS II)	0.06	.459	1.000	23.83 ± 0.39	25.19 ± 15.32	21.03 ± 14.73	.570	0.969	0–100

Note. $M \pm SD$, p values are from ordinal ANOVAs and χ^2 tests comparing the Worsened PTSD, Chronic PTSD, and Improved PTSD groups as well as from correlations (Pearson) between the change in PTSD symptoms (RCI_{SRB}) and each clinical variable across the full sample ($N = 187$). q values indicate significance after .05 false-discovery rate correction. Highlighted cells with italicized results indicate significance at $\alpha = .05$. WTAR = Wechsler Test of Adult Reading; CAPS-IV = Clinician-Administered PTSD Scale for *Diagnostic and Statistical Manual of Mental Disorders, fourth edition*; DASS = Depression, Anxiety, and Stress Scale; mTBI = mild traumatic brain injury; MPQ = McGill Pain Questionnaire; PSQI = Pittsburg Sleep Quality Index; WHODAS II = World Health Organization Disability Assessment Schedule II; RCI = reliable change index; ANOVAs = analyses of variance; PTSD = posttraumatic stress disorder; SRB = standardized regression-based model; LDH = lifetime drinking history. Ranges are the minimum and maximum of each measure. For measures that do not have a minimum or maximum, [ ] are used to refer to ranges within the sample.
* $p < .05$.

Association Between Baseline Alcohol Use and PTSD Symptom Change

We next examined the hypothesized relationships between baseline current and lifetime alcohol use with PTSD symptom changes. For baseline current alcohol use, we first performed correlations between average and maximum drinks on a drinking day. We found that drinks on a drinking day at baseline did not significantly predict PTSD RCI$_{SRB}$ change (*average*: $r = .11$, $p = .121$; *max*: $r = .07$, $p = .320$). Consistent with this, we also failed to find significant differences between Worsened, Chronic, and Improved groups in baseline average drinks on a drinking day, $F(183) = 2.70$, $p = .102$. However, the maximum drinks on a drinking day significantly differed between groups, *maximum*: $F(183) = 4.59$, $p = .033$. We also found that the Improved PTSD group had a trend towards a lower rate of baseline current alcohol use disorder (0.00%) compared to Worsened (17.86%) or Chronic (20.00%) PTSD groups, $\chi^2(2) = 4.93$, $p = .085$.

We next examined the relationship between LDH and PTSD RCI$_{SRB}$ change. We found that *higher* lifetime alcohol consumption at baseline was significantly associated with *worsening* PTSD symptoms ($r = .24$, $p = .001$, see Table 2). Consistent with this, we found that the Worsened PTSD group had significantly greater lifetime alcohol consumption compared to the Chronic or Improved groups, $F(182) = 6.73$, $p = .010$. The difference was driven by the Worsened and Improved groups, Improved $M = 7.69$, $SD = 1.40$, Worsened $M = 6.69$, $SD = 1.97$, $t(147) = .04$. Other comparisons between alcohol measures and PTSD change groups were not significant.

To better characterize these differences in lifetime drinking, similar to previous studies (e.g., Jacob et al., 2013), we next examined the distinct drinking phases from the LDH starting from the earliest age at which at least one alcoholic drink per month was consumed regularly (see Figure 1 and Supplemental Figure S2, for a comparison of the Worsened, Chronic, and Improved PTSD groups). Using an ANCOVA with average drinks on a drinking day as the dependent measure, lifetime drinking phase as a factor (1, 2, or 3), and PTSD RCI$_{SRB}$ as a covariate of interest, we found a significant main effect of phase, $F(158) = 4.15$, $p = .043$, where Phase 1 drinking was significantly lower than Phases 2 and 3 ($M = 5.56$; 7.68; 7.91, respectively, $p < .001$). We also found a significant interaction between phase and RCI$_{SRB}$, $F(158) = 6.51$, $p = .012$, where there was a greater relationship between RCI$_{SRB}$ and average drinks on a drinking day for Phase 3 ($r = .18$, $p = .027$) than Phases 1 or 2 ($r = -.03$ and $-.03$, $p = .659$ and .696). We found a similar pattern of results when examining the Improved, Chronic, and Worsened PTSD groups. Specifically, a repeated-measures ANOVA revealed a significant Group × Phase (Phases 1–3 included) interaction when predicting average drinks on a drinking day, $F(2, 157) = 3.96$, $p = .004$. As can be seen in Figure 1, compared to Phase 2, during Phase 3 the Improved PTSD group *reduced* their average drinks on a drinking day, whereas the Worsened and Chronic PTSD groups *increased* their average drinks. In Phase 3, the Worsened PTSD group's average number of drinks on a drinking day ($M = 10.35$, $SD = 9.91$) was nearly double that of the Improved group ($M = 5.24$, $SD = 3.97$, $p = .026$), and a similar pattern was observed for the max drinks on a drinking day (Worsened PTSD $M = 16.52$, $SD = 12.60$; Improved PTSD $M = 8.74$, $SD = 7.54$, $p = .028$) and the rate of binge drinking during this phase (85.71% of the Worsened PTSD; 47.62% of the Improved PTSD group, $p = .004$).

This divergent pattern between the Improved PTSD and Worsened PTSD groups remained for all subsequent phases. The shift during Phase 3 in individuals' early-to-mid 20s is notable, as it coincides with the average age of military enlistment at 21 (Reynolds & Shendruk, 2018) and suggests that drinking more versus less during this time has important implications for recovering from postdeployment PTSD.

Association Between Baseline Cognitive Performance and PTSD Symptom Changes

We next examined relationships between baseline cognitive performance and PTSD changes over time, focusing on the hypothesized executive function subdomain of inhibitory control. As can be seen in Table 3, we found that better inhibitory control performance (composite of CWI Inhibition and Inhibition/Switching) was significantly associated with greater PTSD improvements over time (RCI$_{SRB}$), $r = -.18$, $p = .017$, with the Inhibition/Switching task having a numerically stronger relationship with PTSD change ($r = -.19$, $p = .012$) than the Inhibition task ($r = -.13$, $p = .094$). When examining the composite of executive functions *excluding* inhibitory control measures (Trail Making Test Number/Letter Switching, FAS-Letter Fluency, Category Switching, IED, ACT), we did not find a significant relationship with PTSD change ($r = -.08$, $p = .262$), suggesting that this association is more specific to inhibitory control rather than other executive functions. We further confirmed the specificity of inhibitory control by performing stepwise linear regression models predicting PTSD RCI$_{SRB}$ scores using all of our executive function measures. Both backward and forward stepwise regressions identified the model with composite inhibitory control as the only predictor resulting in the best model fit, $F(1, 166) = 5.77$, $p = .017$.

Corroborating these findings, we found that composite inhibitory control also significantly differed between the Improved, Chronic, and Worsened PTSD groups, *Worsened*: $M = -0.15$, $SD = 0.85$; *Chronic*: $M = 0.02$, $SD = .82$; *Improved*: $M = 0.39$, $SD = 0.47$, $F(166) = 5.018$, $p = .026$, where the difference was driven by the Improved group, which had significantly greater composite inhibitory control scores than both the Worsened and Chronic groups, $t(43) = -2.569$, $p = .014$; $t(141) = -1.995$, $p = .048$, respectively.

Finally, when examining verbal learning and memory composite from the CVLT-II, we did not observe any associations with PTSD symptom change or differences between Worsened, Chronic, and Improved groups (all ps > .500).

Comparing LDH and Inhibitory Control in Predicting PTSD Symptom Change

Our results showed that both greater lifetime alcohol consumption and worse inhibitory control at baseline were related to worsening PTSD symptoms over a 2-year period. Previous studies have observed significant associations between inhibitory control performance and drinking behaviors (Carbia et al., 2018), though in the present study these measures were not significantly correlated (lifetime alcohol consumption and composite inhibitory control, $r = -.07$, $p = .396$). A regression model including the composite inhibitory control and lifetime alcohol consumption as predictors of PTSD symptom change (RCI$_{SRB}$) was significant, $F(2, 164) = 7.67$, $p \le .001$, adjusted $R^2 = 0.074$, and both composite inhibitory control and lifetime alcohol

Figure 1

Lifetime Drinking History in Groups With Worsened, Chronic, or Improved PTSD
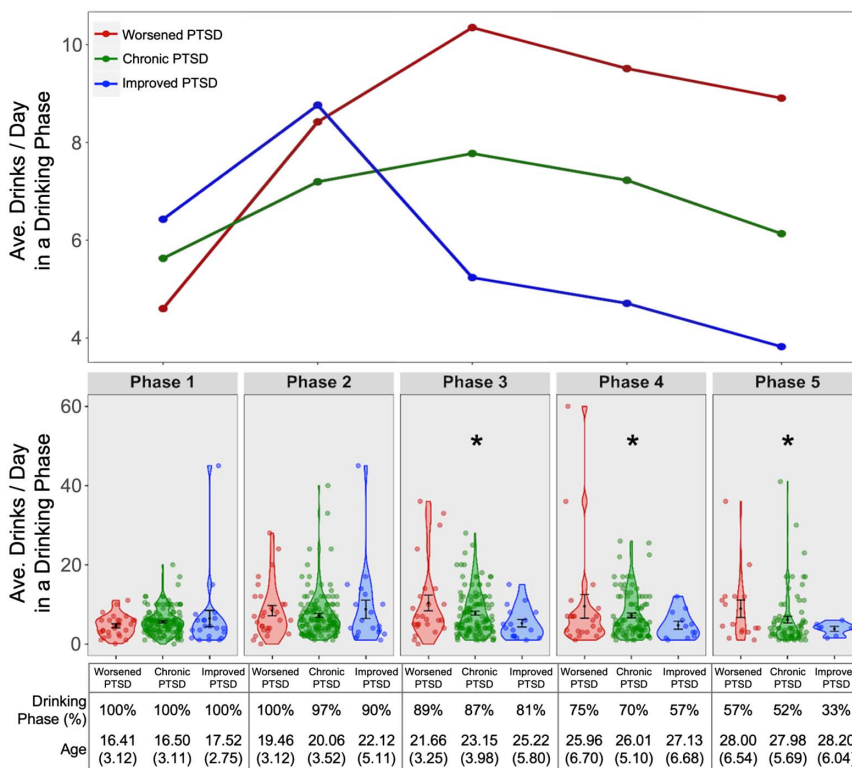
Note. Each line in the top panel represents the average drinks on a drinking day within each phase for the Worsened PTSD (red), Chronic PTSD (green), and Improved PTSD groups (blue). In the lower panel, the distribution of average drinks on a drinking day for each phase is displayed for the Worsened PTSD (red), Chronic PTSD (green), Improved PTSD groups (blue). The error bars reflect the standard error of the mean for each group. Within the table, Drinking Phase (%) indicates the percent of individuals within each group who reported that phase of drinking, as not every individual had multiple phases of drinking throughout their lifetime. A phase shift represents a clinically meaningful change in drinking behaviors defined by quantity and/or frequency. Age reflects the average age at which the drinking phase started. PTSD = posttraumatic stress disorder. See the online article for the color version of this figure.
*Significant differences between the Improved, Chronic, and Worsened PTSD groups.

consumption significantly predicted unique variance in PTSD symptom changes (betas = −.17 and .23; p = .022 and .003, respectively). Both variables remained significant predictors when controlling for additional covariates (estimated premorbid intelligence quotient, age, and education), which did not account for any additional variance in PTSD symptom changes (see Model 3 in Table 4).

Can Treatment Engagement Explain Individual Differences in PTSD Change?

There were no differences between Worsened, Chronic, and Improved groups in treatment participation (see Methods for treatment participation description), including the three broad treatment types (psychotherapy only, medication management only, and combined treatment; see Supplemental Materials for more details), during the interval between baseline and follow-up ($\chi^2(2)$ = 1.42, p = .491). Specifically, 71.43% of the Worsened PTSD group, 84.00% of the Chronic PTSD group, and 61.91% of the Improved PTSD participated in some form of treatment (e.g., medication management

or psychotherapy). All analyses were repeated after removing those participants with missing treatment frequency data, and group differences yielded identical results (see Supplemental Results and Supplemental Table S4). Thus, additional factors such as inhibitory control and LDH likely contributed to PTSD symptom changes above and beyond the effects of engaging in treatment.

Associations Between PTSD Changes With Changes in Inhibitory Control and Alcohol Use

Though a full examination of relationships between changes in clinical and cognitive variables with PTSD symptom changes is beyond the scope of this study, these analyses can be found in the Supplemental Materials (Supplemental Tables S5 and S6). Relevant to the current findings, we did find that increases in the average and max drinks consumed on drinking days between the two time points were not significantly associated with increased PTSD symptoms over time (r = .10, p = .165; r = .06, p = .443, respectively). All groups decreased their max drinks on a drinking day between time

Table 3
Associations Between Baseline Cognitive Measures and PTSD Changes Over Time

Domain	Measure	PTSD+			Worsened PTSD	Chronic PTSD	Improved PTSD	p	q	Range
		r	p	q						
EF	Inhibitory Control Composite	-0.18	.017*	—	-0.15 ± 0.85	0.02 ± 0.82	0.39 ± 0.47	.026*	—	[-3.00–1.67]
	D-KEFS Color-Word Inhibition	-0.13	.094	—	0.03 ± 0.94	0.10 ± 0.89	0.45 ± 0.54	.121	—	[-3.00–1.67]
	D-KEFS Color-Word Inhibition/Switching	-0.18	.019*	—	-0.33 ± 0.99	-0.07 ± 0.96	0.33 ± 0.54	.018*	—	[-3.00–1.33]
	EF Composite Without Inhibitory Control	-0.08	.262	0.721	-0.73 ± .62	-0.09 ± .053	0.09 ± 0.37	.358	1.000	[-1.55–1.78]
	Trails B	-0.04	.586	0.921	0.07 ± 1.05	-0.26 ± 0.91	0.35 ± 0.46	.363	0.882	[-3.00–1.67]
	FAS Letter Fluency	-0.10	.195	0.715	0.10 ± 1.05	0.24 ± 1.07	0.45 ± 1.21	.289	1.000	[-2.33–3.00]
	FAS Category Switching	-0.08	.287	0.631	0.31 ± 1.23	0.51 ± 1.02	0.72 ± 1.04	.192	1.000	[-2.67–3.00]
	CANTAB IED	0.01	.917	1.000	-0.03 ± 0.97	-0.17 ± 0.98	0.06 ± 0.71	.854	0.940	[-2.25–3.73]
	ACT	-0.11	.187	1.000	-0.76 ± 0.91	-0.44 ± 1.06	-0.30 ± 1.06	.151	1.000	[-3.46–2.58]
Verbal memory	Verbal Memory Composite	0.02	.820	1.000	-0.34 ± 1.13	-0.33 ± 0.95	-0.27 ± 0.87	.819	0.994	[-3.50–1.33]
	CVLT-II Verbal Learning Total Trails 1–5	-0.01	.865	1.000	-0.32 ± 1.27	-0.10 ± 1.00	-.124 ± 0.90	.466	1.000	[-3.40–2.10]
	CVLT-II Short-Delay Free Recall	0.05	.501	0.919	-0.13 ± 1.11	-.14 ± 1.07	-0.19 ± 0.83	.849	0.995	[-3.50–2.00]
	CVLT-II Long-Delay Free Recall	0.00	.985	0.985	-0.24 ± 1.32	0.24 ± 1.09	-0.10 ± 1.02	.683	0.968	[-3.00–1.50]
	CVLT-II Recognition Hits	0.00	.953	1.000	-0.65 ± 1.28	-0.62 ± 1.17	-0.52 ± 1.27	.733	0.959	[-5.00–1.50]

Note. $M \pm SD$. p values are from Pearson correlations between change in PTSD (RCI_{SRB}) and each cognitive variable as well as ordinal ANOVAs comparing the Worsened PTSD, Chronic PTSD, and Improved PTSD groups. q values indicate significance after false-discovery rate correction. Highlighted cells with italicized results indicate significance at $\alpha = .05$. CVLT-II = California Verbal Learning Test–Second Edition; D-KEFS = Delis–Kaplan Executive Function System; IED = Intra–Extra Dimensional Set Shift; ACT = Auditory Consonant Trigrams; PTSD = posttraumatic stress disorder; SRB = standardized regression-based model; ANOVAs = analyses of variance; CANTAB = Cambridge Neuropsychological Test Automated Battery; EF = executive functioning. Ranges are the minimum and maximum of each measure. For measures that do not have a minimum or maximum, [ ] are used to refer to ranges within the sample.
* $p < .05$.

Table 4

Linear Regression Models Predicting Reliable Change in PTSD (RCI_SRB) in the Full Sample

Predictors	Model 1	Model 2	Model 3
Inhibitory control composite	−0.18* *(0.23)*	−0.17* *(0.23)*	−0.18* *(0.24)*
Log total lifetime drinks (weight-adjusted; LDH)		0.23** *(0.13)*	0.21** *(0.13)*
Estimated premorbid intelligence (WTAR)			0.07 *(0.02)*
Age			0.09 *(0.02)*
Education			−0.01 *(0.11)*
Adjusted R^2	0.03	0.07	0.07
Model p	.017	<.001	.006

Note. Values represent standardized betas and the betas' associated standard error is italicized in parentheses. RCI = reliable change index; LDH = Lifetime Drinking History; WTAR = Wechsler Test of Adult Reading; PTSD = posttraumatic stress disorder; SRB = standardized regression-based model.
* $p < .05$.   ** $p < .01$.

points, and for average drinks on a drinking day, the Worsened group alone numerically increased, albeit nonsignificantly (baseline: $M = 8.18$ $SD = 5.32$; follow-up: $M = 8.50$ $SD = 6.38$; $q = .975$, see Supplemental Materials). Further, we found that PTSD symptom changes were not associated with changes in the composite inhibitory control score ($r = −.13$, $p = .095$). In general, inhibitory control scores improved over time for all three groups, though this was not significant in any single group after FDR correction, except in the Chronic PTSD group (baseline $M = .03$, $SD = .80$; follow-up $M = .35$, $SD = .88$; $q < .001$).

Discussion

This study utilized a well-characterized sample of 187 post-9/11 veterans with a diagnosis of baseline PTSD who were assessed approximately 2 years later and examined predictors of continuous PTSD symptom changes as well as differences between subgroups with significantly Improved, Worsened, or Chronic PTSD. Our results revealed several important and novel findings. First, we found that better baseline inhibitory control abilities as measured by the Color-Word Interference Test (i.e., Stroop), but not other executive functions or memory abilities, were specifically associated with greater PTSD symptom improvements over time. We also found that veterans' drinking history over the past 10–15 years was significantly associated with changes in PTSD symptoms over time, more so than baseline current alcohol consumption. Finally, our results suggest that reduced inhibitory control and elevated prolonged drinking behavior act more as stable traits/preexisting risk factors for chronic and worsening PTSD rather than the effects of PTSD symptomatology. These findings provide insights into the factors affecting the progression and chronicity of PTSD and may have important treatment implications.

In veterans with a baseline diagnosis of PTSD, we found that improvements in PTSD symptoms over a 2-year period were significantly associated with better baseline inhibitory control performance, though PTSD improvements were not significantly associated with other executive functions or cognitive measures. This specific effect was also found when examining the separate PTSD change subgroups (see Table 2), with the Improved PTSD group showing significantly better baseline inhibitory control performance than the Chronic and Worsened PTSD groups. These findings suggest that inhibitory control deficits play a role in the maintenance of PTSD symptoms and that individuals with PTSD

and above-average inhibitory control abilities may experience better long-term PTSD outcomes compared to those with poorer inhibitory control abilities. This is consistent with studies demonstrating that poorer pretrauma inhibitory control is a risk factor for developing PTSD after trauma exposure (Samuelson et al., 2020), that inhibitory control is specifically related to greater PTSD symptoms beyond general executive functions in a trauma-exposed population (DeGutis et al., 2015), and that inhibitory control deficits play a role in maintaining PTSD symptoms (Aupperle et al., 2012). The present study extends these studies by demonstrating that, even in those who meet diagnostic criteria for PTSD, above-average inhibitory control abilities can serve as a protective factor against chronic or worsening PTSD symptoms.

These results are more consistent with a model of PTSD in which inhibitory control represents a preexisting risk factor or protective trait rather than strictly a consequence of PTSD. Though we found that better baseline composite inhibitory control performance predicted PTSD symptom improvements, PTSD symptom changes between time points were *not* significantly associated with changes in composite inhibitory control performance over time. This emphasizes the importance of more stable inhibitory control abilities to PTSD chronicity rather than inhibitory control tracking PTSD severity. This is consistent with results from a recent PTSD study of trauma-focused therapy. Crocker et al. (2018) found that, in post-9/11 veterans with PTSD, worse baseline executive functioning (including inhibition, inhibition/switching, and working memory) predicted poorer CPT outcomes. Further, the addition of compensatory cognitive training targeting executive functions to CPT allowed those with worse inhibitory control to benefit more from therapy (Crocker et al., 2018). These findings, along with the current results and neuroimaging findings during inhibitory control tasks predicting treatment responses (Bryant et al., 2021; Falconer et al., 2013), support a model in which preexisting inhibitory control abilities affect the maintenance of PTSD symptoms as well as treatment success (Aupperle et al., 2012). Contrasting this model, Haaland et al. (2016) found that, in female veterans with PTSD, only baseline learning/memory performance predicted PTSD trauma-focused treatment success, whereas inhibition and inhibition/switching improvements were associated with PTSD improvements after treatment. Additional studies would be useful to further characterize whether inhibitory control plays more of a prominent role as a preexisting factor/predictor of PTSD chronicity and treatment success versus a correlate of PTSD symptomatology, as well as

determine if this relationship is moderated by gender or the type of trauma exposure.

In addition to showing the contribution of inhibitory control to PTSD chronicity, the current results also demonstrated that alcohol use significantly predicted changes in PTSD symptoms. Notably, LDH over the last 10–15 years (starting around the age of typical military enlistment) was a stronger predictor of PTSD change than current alcohol use. In particular, the Improved group had less lifetime alcohol consumption than the Chronic and Worsened groups, suggesting that lower lifetime alcohol consumption may be a protective factor against more long-term PTSD. We observed a significant differentiation in drinking habits in the early-to-mid 20s that was maintained throughout subsequent drinking phases, with the Improved PTSD group decreasing their alcohol consumption during this period and with Worsened/Chronic PTSD groups increasing alcohol consumption. To our knowledge, this is the first study to demonstrate a relationship between alcohol-related behaviors across lifetime drinking phases and PTSD symptom changes. Though the greater association of previous versus current drinking behavior to PTSD changes is notable, it could be possible that previous drinking behavior is simply a more reliable and valid measure than current drinking because participants may be more willing to endorse past alcohol problems and may minimize or underreport current drinking (Neumann et al., 2009).

Our results demonstrating the contribution of drinking history to PTSD changes, along with finding that alcohol use changes over 2 years show little-to-no correlations with PTSD changes, provide support for the self-medication rather than the mutual maintenance model of alcohol use in PTSD. Both models predict that PTSD is associated with higher alcohol use, and indeed, we found that veterans in the present study had ~2–4 times the alcohol consumption of the general U.S. population (Chan et al., 2007). However, only the mutual maintenance model predicts that increases in alcohol use would be associated with worsened PTSD symptoms (Simpson et al., 2014), which the current results do not support (PTSD change vs. change in average drinks: $r = .10$, $p = .165$; vs. change max drinks: $r = .06$, $p = .443$). Our finding is consistent with previous longitudinal studies of PTSD and alcohol use across 2 years (Kaysen et al., 2006, 2011; Langdon et al., 2016; Nickerson et al., 2014). Though these results are promising, using more fine-grained temporal assessments of alcohol consumption and PTSD symptoms (e.g., using ecological momentary assessments) over days/weeks rather than months/years would be important to confirm these findings (Khantzian, 1997; Tripp et al., 2020).

Taken together, these results suggest that PTSD symptom chronicity is not significantly related to baseline alcohol consumption (except when considering maximum drinks), nor is it related to changes in alcohol consumption between time points. Rather, the results support the effects of lifetime drinking quantity on PTSD symptom changes. One possibility is that LDH may better capture more trait-based or preexisting differences in behavioral impulsivity (Gröpper et al., 2016; Nigg et al., 2006) than current alcohol consumption. For example, in Phase 3, the Improved Group, compared to the Chronic and Worsened groups, may have had or exerted more self-control that allowed them to dampen their drinking behaviors, and this was maintained through their subsequent drinking phases. Behavioral impulsivity is a multifaceted personality disposition related to deficient emotional or behavioral self-control in everyday life decisions (Duckworth & Kern, 2011;

Whiteside & Lynam, 2001) and is a related but distinct construct from inhibitory control, which represents the ability to override impulses to accomplish a goal-directed task (Sadeh et al., 2015). Behavioral impulsivity is consistently related to higher alcohol use (e.g., in veterans with PTSD symptoms; see Mahoney et al., 2020), and several aspects of behavioral impulsivity could also play a role in maintaining PTSD symptoms, such as difficulty with emotion regulation and a propensity toward risky behavior (a PTSD diagnostic item in the *Diagnostic and Statistical Manual of Mental Disorders, fifth edition*). Future work would be useful to examine whether specific aspects of behavioral impulsivity are related to the chronicity of PTSD symptoms.

The results of the present study have potentially important clinical and treatment implications. First, they suggest that individuals with PTSD and poorer inhibitory control and/or greater LDH are at an increased risk for chronic PTSD and should be more closely monitored and potentially targeted with interventions. All groups generally improved in the inhibitory control tasks across timepoints, suggesting that improvements may be a practice effect. However, Worsened and Chronic groups never reached the Improved group's performance on inhibitory control tasks (see Supplemental Table S3). Our results suggest that interventions specifically targeting inhibitory control may be particularly beneficial and, similar to Crocker et al. (2018), could be readily paired with trauma-focused therapies to reduce PTSD symptoms. These include computer-based inhibitory training programs shown to improve PTSD symptoms, such as attentional control training (Badura-Brack et al., 2015; Lazarov et al., 2019), response inhibition training (Echiverri-Cohen et al., 2021), and interference control training (Bomyea et al., 2015). They could also include inhibitory control-enhancing pharmacological interventions such as methylphenidate (McAllister et al., 2016) and cognitive skills training targeting inhibitory control (Fortier et al., 2018; Maraver et al., 2016). The current results also highlight the utility in clinically assessing alcohol use across the lifespan beyond just current drinking in individuals with PTSD. Clinicians might benefit from focusing more on the onset of problem drinking, earlier life patterns of alcohol use, and the historical function of alcohol in an individual's life.

Though the current findings are robust and have potentially important implications, there are several limitations, and future studies would be useful to build on these results. First, the sample was composed of mostly male (87%) post-9/11 veterans, and it is unclear if these results apply to females or other types of trauma, necessitating replication in a nonveteran population. Additionally, we assessed participants with a PTSD diagnosis and are unable to determine if inhibitory control differences were present before their diagnosis or trauma exposure. Samuelson et al. (2020) found that in post-9/11 veterans, predeployment inhibitory control performance significantly predicted postdeployment PTSD symptom severity, suggesting that the performance differences we observed may have been present before trauma exposure. It could be that PTSD symptoms further exacerbate inhibitory control abilities (see Vasterling & Arditte Hall, 2018, though our data do not necessarily support this), and this would be important to test in future studies. A third limitation is that baseline inhibitory control and lifetime alcohol use only predicted 7% of the variance in PTSD symptom change. Incorporating additional inhibitory control tasks (e.g., go/no-go task) and including "hot" inhibitory control tasks that use trauma-related or emotional distractors (e.g., emotional Stroop;

Ashley et al., 2013) could allow a better characterization of inhibitory control and greater predictive ability. Also, while we excluded participants based on evidence of reduced effort on the Medical Symptom Validity Test, we did not quantify over versus under-reporting of clinical symptoms, which could have helped with interpretation of PTSD symptom changes. Another limitation is that treatment-related information was obtained from clinical notes/reports, and additional details, such as the length of treatment, were limited. Finally, additional time points would have allowed for a better examination of the trajectory of PTSD symptomology.

The current findings advance the understanding of PTSD in several ways. They suggest that preexisting inhibitory control abilities and early adulthood drinking behavior are significant predictors of the long-term chronicity of PTSD. They also suggest that the associations between PTSD change and inhibitory control/lifetime drinking are specific, with other cognitive, clinical, and alcohol consumption measures not significantly predicting PTSD symptom changes. These findings complement studies showing the importance of inhibitory control and alcohol consumption to the development of PTSD and provide a framework for future investigations into the mechanisms of impulsivity and inhibitory control in PTSD. Finally, the current findings have clear clinical implications, suggesting that clinicians should closely monitor individuals with these risk factors and use innovative targeted interventions such as inhibitory control training and pharmacotherapies to improve PTSD and functional outcomes in this vulnerable group.

References

Ashley, V., Honzel, N., Larsen, J., Justus, T., & Swick, D. (2013). Attentional bias for trauma-related words: Exaggerated emotional Stroop effect in Afghanistan and Iraq war veterans with PTSD. *BMC Psychiatry*, *13*(1), Article 86. https://doi.org/10.1186/1471-244X-13-86

Aupperle, R. L., Melrose, A. J., Stein, M. B., & Paulus, M. P. (2012). Executive function and PTSD: Disengaging from trauma. *Neuropharmacology*, *62*(2), 686–694. https://doi.org/10.1016/j.neuropharm.2011.02.008

Badour, C. L., Blonigen, D. M., Boden, M. T., Feldner, M. T., & Bonn-Miller, M. O. (2012). A longitudinal test of the bi-directional relations between avoidance coping and PTSD severity during and after PTSD treatment. *Behaviour Research and Therapy*, *50*(10), 610–616. https://doi.org/10.1016/j.brat.2012.06.006

Badura-Brack, A. S., Naim, R., Ryan, T. J., Levy, O., Abend, R., Khanna, M. M., McDermott, T. J., Pine, D. S., & Bar-Haim, Y. (2015). Effect of attention training on attention bias variability and PTSD symptoms: Randomized controlled trials in Israeli and US combat veterans. *The American Journal of Psychiatry*, *172*(12), 1233–1241. https://doi.org/10.1176/appi.ajp.2015.14121578

Bardeen, J. R., Gorday, J. Y., & Weathers, F. W. (2022). Executive functioning deficits exacerbate posttraumatic stress symptoms: A longitudinal mediation model. *Journal of Anxiety Disorders*, *87*, Article 102556. https://doi.org/10.1016/j.janxdis.2022.102556

Bedard-Gilligan, M., Garcia, N., Zoellner, L. A., & Feeny, N. C. (2018). Alcohol, cannabis, and other drug use: Engagement and outcome in PTSD treatment. *Psychology of Addictive Behaviors*, *32*(3), 277–288. https://doi.org/10.1037/adb0000355

Berke, D. S., Yeterian, J., Presseau, C., Rusowicz-Orazem, L., Kline, N. K., Nash, W. P., & Litz, B. T. (2019). Dynamic changes in marines' reports of PTSD symptoms and problem alcohol use across the deployment cycle. *Psychology of Addictive Behaviors*, *33*(2), 162–170. https://doi.org/10.1037/adb0000430

Blake, D. D., Weathers, F. W., Nagy, L. M., Kaloupek, D. G., Gusman, F. D., Charney, D. S., & Keane, T. M. (1995). The development of a clinician-administered PTSD scale. *Journal of Traumatic Stress*, *8*(1), 75–90. https://doi.org/10.1002/jts.2490080106

Bohnen, N., Jolles, J., & Twijnstra, A. (1992). Modification of the stroop color word test improves differentiation between patients with mild head injury and matched controls. *The Clinical Neuropsychologist*, *6*(2), 178–184. https://doi.org/10.1080/13854049208401854

Bomyea, J., Stein, M. B., & Lang, A. J. (2015). Interference control training for PTSD: A randomized controlled trial of a novel computer-based intervention. *Journal of Anxiety Disorders*, *34*, 33–42. https://doi.org/10.1016/j.janxdis.2015.05.010

Bonanno, G. A. (2004). Loss, trauma, and human resilience: Have we underestimated the human capacity to thrive after extremely aversive events? *American Psychologist*, *59*(1), 20–28. https://doi.org/10.1037/0003-066X.59.1.20

Bonanno, G. A., & Mancini, A. D. (2012). Beyond resilience and PTSD: Mapping the heterogeneity of responses to potential trauma. *Psychological Trauma: Theory, Research, Practice, and Policy*, *4*(1), 74–83. https://doi.org/10.1037/a0017829

Brewin, C. R. (2005). Risk factor effect sizes in PTSD: What this means for intervention. *Journal of Trauma & Dissociation*, *6*(2), 123–130. https://doi.org/10.1300/J229v06n02_11

Bryant, R. A., Williamson, T., Erlinger, M., Felmingham, K. L., Malhi, G., Hinton, M., Williams, L., & Korgaonkar, M. S. (2021). Neural activity during response inhibition associated with improvement of dysphoric symptoms of PTSD after trauma-focused psychotherapy-an EEG-fMRI study. *Translational Psychiatry*, *11*(1), Article 218. https://doi.org/10.1038/s41398-021-01340-8

Buysse, D. J., Reynolds, C. F., III, Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Research*, *28*(2), 193–213. https://doi.org/10.1016/0165-1781(89)90047-4

Carbia, C., López-Caneda, E., Corral, M., & Cadaveira, F. (2018). A systematic review of neuropsychological studies involving young binge drinkers. *Neuroscience and Biobehavioral Reviews*, *90*, 332–349. https://doi.org/10.1016/j.neubiorev.2018.04.013

Chan, K. K., Neighbors, C., Gilson, M., Larimer, M. E., & Alan Marlatt, G. (2007). Epidemiological trends in drinking by age and gender: Providing normative feedback to adults. *Addictive Behaviors*, *32*(5), 967–976. https://doi.org/10.1016/j.addbeh.2006.07.003

Crocker, L. D., Jurick, S. M., Thomas, K. R., Keller, A. V., Sanderson-Cimino, M., Boyd, B., Rodgers, C., Twamley, E. W., & Jak, A. J. (2018). Worse baseline executive functioning is associated with dropout and poorer response to trauma-focused treatment for veterans with PTSD and comorbid traumatic brain injury. *Behaviour Research and Therapy*, *108*, 68–77. https://doi.org/10.1016/j.brat.2018.07.004

DeGutis, J., Esterman, M., McCulloch, B., Rosenblatt, A., Milberg, W., & McGlinchey, R. (2015). Posttraumatic psychological symptoms are associated with reduced inhibitory control, not general executive dysfunction. *Journal of the International Neuropsychological Society*, *21*(5), 342–352. https://doi.org/10.1017/S1355617715000235

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan executive function system*.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Duckworth, A. L., & Kern, M. L. (2011). A meta-analysis of the convergent validity of self-control measures. *Journal of Research in Personality*, *45*(3), 259–268. https://doi.org/10.1016/j.jrp.2011.02.004

Echiverri-Cohen, A., Spierer, L., Perez, M., Kulon, M., Ellis, M. D., & Craske, M. (2021). Randomized-controlled trial of response inhibition training for individuals with PTSD and impaired response inhibition. *Behaviour Research and Therapy*, *143*, Article 103885. https://doi.org/10.1016/j.brat.2021.103885

Elwood, L. S., Hahn, K. S., Olatunji, B. O., & Williams, N. L. (2009). Cognitive vulnerabilities to the development of PTSD: A review of four

vulnerabilities and the proposal of an integrative vulnerability model. *Clinical Psychology Review*, *29*(1), 87–100. https://doi.org/10.1016/j.cpr.2008.10.002

Esterman, M., Fortenbaugh, F. C., Pierce, M. E., Fonda, J. R., DeGutis, J., Milberg, W., & McGlinchey, R. (2019). Trauma-related psychiatric and behavioral conditions are uniquely associated with sustained attention dysfunction. *Neuropsychology*, *33*(5), 711–724. https://doi.org/10.1037/neu0000525

Falconer, E., Allen, A., Felmingham, K. L., Williams, L. M., & Bryant, R. A. (2013). Inhibitory neural activity predicts response to cognitive-behavioral therapy for posttraumatic stress disorder. *The Journal of Clinical Psychiatry*, *74*(9), 895–901. https://doi.org/10.4088/JCP.12m08020

First, M. B. (1997). *Structured clinical interview for DSM-IV axis I disorders*. Biometrics Research Department.

Fortier, C. B., Amick, M. M., Grande, L., McGlynn, S., Kenna, A., Morra, L., Clark, A., Milberg, W. P., & McGlinchey, R. E. (2014). The Boston Assessment of Traumatic Brain Injury-Lifetime (BAT-L) semistructured interview: Evidence of research utility and validity. *The Journal of Head Trauma Rehabilitation*, *29*(1), 89–98. https://doi.org/10.1097/HTR.0b013e3182865859

Fortier, C. B., Kenna, A., Dams-O'Connor, K., Fonda, J., Levin, L. K., Hursh, C., Franz, H., Milberg, W. P., & McGlinchey, R. E. (2018). Feasibility of a skills-based group reintegration workshop for OEF/OIF Veterans: STEP-home. *The Journal of Head Trauma Rehabilitation*, *33*(4), E17–E23. https://doi.org/10.1097/HTR.0000000000000362

Fortier, C. B., Steffen, E. M., LaFleche, G., Venne, J. R., Disterhoft, J. F., & McGlinchey, R. E. (2008). Delay discrimination and reversal eyeblink classical conditioning in abstinent chronic alcoholics. *Neuropsychology*, *22*(2), 196–208. https://doi.org/10.1037/0894-4105.22.2.196

Fortier, C. B., Whitworth, J. W., Fonda, J. R., Currao, A., Beck, B. M., Levin, L., Esterman, M., Milberg, W. P., & McGlinchey, R. E. (2021). Early adolescent binge drinking increases risk of psychopathology in post-9/11 veterans and mild traumatic brain injury exacerbates symptom severity. *Alcohol and Alcoholism*, *56*(1), 116–124. https://doi.org/10.1093/alcalc/agaa075

Friedman, M. J., Schnurr, P. P., & McDonagh-Coyle, A. (1994). Posttraumatic stress disorder in the military veteran. *The Psychiatric Clinics of North America*, *17*(2), 265–277. https://doi.org/10.1016/S0193-953X(18)30113-8

Galatzer-Levy, I. R., Ma, S., Statnikov, A., Yehuda, R., & Shalev, A. Y. (2017). Utilization of machine learning for prediction of post-traumatic stress: A re-examination of cortisol in the prediction and pathways to non-remitting PTSD. *Translational Psychiatry*, *7*(3), Article e1070. https://doi.org/10.1038/tp.2017.38

Gmel, G., Rehm, J., Room, R., & Greenfield, T. K. (2000). Dimensions of alcohol-related social and health consequences in survey research. *Journal of Substance Abuse*, *12*(1–2), 113–138. https://doi.org/10.1016/S0899-3289(00)00044-4

Green, P. (2004). *Green's Medical Symptom Validity Test (MSVT)*. *User's Manual*. Green's Publishing.

Gröpper, S., Spengler, S., Stuke, H., Gawron, C. K., Parnack, J., Gutwinski, S., Wiers, C. E., & Bermpohl, F. (2016). Behavioral impulsivity mediates the relationship between decreased frontal gray matter volume and harmful alcohol drinking: A voxel-based morphometry study. *Journal of Psychiatric Research*, *83*, 16–23. https://doi.org/10.1016/j.jpsychires.2016.08.006

Haaland, K. Y., Sadek, J. R., Keller, J. E., & Castillo, D. T. (2016). Neurocognitive correlates of successful treatment of PTSD in female veterans. *Journal of the International Neuropsychological Society*, *22*(6), 643–651. https://doi.org/10.1017/S1355617716000424

Hawn, S. E., Cusack, S. E., & Amstadter, A. B. (2020). A systematic review of the self-medication hypothesis in the context of posttraumatic stress disorder and comorbid problematic alcohol use. *Journal of Traumatic Stress*, *33*(5), 699–708. https://doi.org/10.1002/jts.22521

Henry, J. D., & Crawford, J. R. (2005). The short-form version of the Depression Anxiety Stress Scales (DASS-21): Construct validity and normative data in a large non-clinical sample. *British Journal of Clinical Psychology*, *44*(2), 227–239. https://doi.org/10.1348/014466505X29657

Hinton-Bayre, A. D. (2016). Clarifying discrepancies in responsiveness between reliable change indices. *Archives of Clinical Neuropsychology*, *31*(7), 754–768. https://doi.org/10.1093/arclin/acw064

Holzman, J. B., Valentiner, D. P., Hannan, S. M., Wallace, D. G., & Orcutt, H. K. (2017). High dose alcohol consumption predicts less reduction in post-traumatic stress symptoms after a campus mass shooting. *Anxiety, Stress, and Coping*, *30*(6), 609–618. https://doi.org/10.1080/10615806.2017.1348297

Jacob, T., Blonigen, D. M., Upah, R., & Justice, A. (2013). Lifetime drinking trajectories among veterans in treatment for HIV. *Alcoholism, Clinical and Experimental Research*, *37*(7), 1179–1187. https://doi.org/10.1111/acer.12071

Jacobsen, L. K., Southwick, S. M., & Kosten, T. R. (2001). Substance use disorders in patients with posttraumatic stress disorder: a review of the literature. American *Journal of Psychiatry*, *158*(8), 1184–1190. https://doi.org/10.1176/appi.ajp.158.8.1184

Kamphuis, W., Delahaij, R., Duel, J., Geuze, E., & Vermetten, E. (2021). The relationship between resilience resources and long-term deployment-related PTSD symptoms: A longitudinal study in dutch veterans. *Military Behavioral Health*, *9*(3), 267–274. https://doi.org/10.1080/21635781.2020.1864528

Karstoft, K. I., Armour, C., Elklit, A., & Solomon, Z. (2015). The role of locus of control and coping style in predicting longitudinal PTSD-trajectories after combat exposure. *Journal of Anxiety Disorders*, *32*, 89–94. https://doi.org/10.1016/j.janxdis.2015.03.007

Kaysen, D., Atkins, D. C., Moore, S. A., Lindgren, K. P., Dillworth, T., & Simpson, T. (2011). Alcohol use, problems, and the course of posttraumatic stress disorder: A prospective study of female crime victims. *Journal of Dual Diagnosis*, *7*(4), 262–279. https://doi.org/10.1080/15504263.2011.620449

Kaysen, D., Simpson, T., Dillworth, T., Larimer, M. E., Gutner, C., & Resick, P. A. (2006). Alcohol problems and posttraumatic stress disorder in female crime victims. *Journal of Traumatic Stress*, *19*(3), 399–403. https://doi.org/10.1002/jts.20122

Khantzian, E. J. (1997). The self-medication hypothesis of substance use disorders: A reconsideration and recent applications. *Harvard Review of Psychiatry*, *4*(5), 231–244. https://doi.org/10.3109/10673229709030550

Koob, G. F., & Volkow, N. D. (2010). Neurocircuitry of addiction. *Neuropsychopharmacology*, *35*(1), 217–238. https://doi.org/10.1038/npp.2009.110

Langdon, K. J., Fox, A. B., King, L. A., King, D. W., Eisen, S., & Vogt, D. (2016). Examination of the dynamic interplay between posttraumatic stress symptoms and alcohol misuse among combat-exposed Operation Enduring Freedom (OEF)/Operation Iraqi Freedom (OIF) Veterans. *Journal of Affective Disorders*, *196*, 234–242. https://doi.org/10.1016/j.jad.2016.02.048

Lazarov, A., Suarez-Jimenez, B., Abend, R., Naim, R., Shvil, E., Helpman, L., Zhu, X., Papini, S., Duroski, A., Rom, R., Schneier, F. R., Pine, D. S., Bar-Haim, Y., & Neria, Y. (2019). Bias-contingent attention bias modification and attention control training in treatment of PTSD: A randomized control trial. *Psychological Medicine*, *49*(14), 2432–2440. https://doi.org/10.1017/S0033291718003367

Lee, D. J., Bryan, C. J., & Rudd, M. D. (2020). Longitudinal suicide ideation trajectories in a clinical trial of brief CBT for U.S. military personnel recently discharged from psychiatric hospitalization. *Psychiatry Research*, *293*, Article 113335. https://doi.org/10.1016/j.psychres.2020.113335

Lee, D. J., Lee, L. O., Bovin, M. J., Moshier, S. J., Dutra, S. J., Kleiman, S. E., Rosen, R. C., Vasterling, J. J., Keane, T. M., & Marx, B. P. (2020). The 20-year course of posttraumatic stress disorder symptoms among veterans. *Journal of Abnormal Psychology*, *129*(6), 658–669. https://doi.org/10.1037/abn0000571

Lovibond, P. F., & Lovibond, S. H. (1995). The structure of negative emotional states: Comparison of the Depression Anxiety Stress Scales

(DASS) with the Beck Depression and Anxiety Inventories. *Behaviour Research and Therapy*, 33(3), 335–343. https://doi.org/10.1016/0005-7967(94)00075-U

Mahoney, C. T., Cole, H. E., Gilbar, O., & Taft, C. T. (2020). The role of impulsivity in the association between posttraumatic stress disorder symptom severity and substance use in male military veterans. *Journal of Traumatic Stress*, 33(3), 296–306. https://doi.org/10.1002/jts.22508

Maksimovskiy, A. L., McGlinchey, R. E., Fortier, C. B., Salat, D. H., Milberg, W. P., & Oscar-Berman, M. (2014). White matter and cognitive changes in veterans diagnosed with alcoholism and PTSD. *Journal of Alcoholism and Drug Dependence*, 2(1), 144. https://doi.org/10.4172/2329-6488.1000144

Maraver, M. J., Bajo, M. T., & Gomez-Ariza, C. J. (2016). Training on working memory and inhibitory control in young adults. *Frontiers in Human Neuroscience*, 10, Article 588. https://doi.org/10.3389/fnhum.2016.00588

Marmar, C. R., Schlenger, W., Henn-Haase, C., Qian, M., Purchia, E., Li, M., Corry, N., Williams, C. S., Ho, C. L., Horesh, D., Karstoft, K. I., Shalev, A., & Kulka, R. A. (2015). Course of posttraumatic stress disorder 40 years after the Vietnam War: Findings from the National Vietnam Veterans Longitudinal Study. *JAMA Psychiatry*, 72(9), 875–881. https://doi.org/10.1001/jamapsychiatry.2015.0803

Marx, B. P., Doron-Lamarca, S., Proctor, S. P., & Vasterling, J. J. (2009). The influence of pre-deployment neurocognitive functioning on post-deployment PTSD symptom outcomes among Iraq-deployed Army soldiers. *Journal of the International Neuropsychological Society*, 15(6), 840–852. https://doi.org/10.1017/S1355617709990488

McAllister, T. W., Zafonte, R., Jain, S., Flashman, L. A., George, M. S., Grant, G. A., He, F., Lohr, J. B., Andaluz, N., Summerall, L., Paulus, M. P., Raman, R., & Stein, M. B. (2016). Randomized placebo-controlled trial of methylphenidate or galantamine for persistent emotional and cognitive symptoms associated with PTSD and/or traumatic brain injury. *Neuropsychopharmacology*, 41(5), 1191–1198. https://doi.org/10.1038/npp.2015.282

McFarlane, A. C., Browne, D., Bryant, R. A., O'Donnell, M., Silove, D., Creamer, M., & Horsley, K. (2009). A longitudinal analysis of alcohol consumption and the risk of posttraumatic symptoms. *Journal of Affective Disorders*, 118(1–3), 166–172. https://doi.org/10.1016/j.jad.2009.01.017

McGlinchey, R. E., Milberg, W. P., Fonda, J. R., & Fortier, C. B. (2017). A methodology for assessing deployment trauma and its consequences in OEF/OIF/OND veterans: The TRACTS longitudinal prospective cohort study. *International Journal of Methods in Psychiatric Research*, 26(3), Article e1556. https://doi.org/10.1002/mpr.1556

McSweeny, A. J., Naugle, R. I., Chelune, G. J., & Lüders, H. (1993). "T scores for change": An illustration of a regression approach to depicting change in clinical neuropsychology. *Clinical Neuropsychologist*, 7(3), 300–312. https://doi.org/10.1080/13854049308401901

Melzack, R. (1975). The McGill Pain Questionnaire: Major properties and scoring methods. *Pain*, 1(3), 277–299. https://doi.org/10.1016/0304-3959(75)90044-5

Neumann, T., Gentilello, L. M., Neuner, B., Weiss-Gerlach, E., Schürmann, H., Schröder, T., Müller, C., Haas, N. P., & Spies, C. D. (2009). Screening trauma patients with the alcohol use disorders identification test and biomarkers of alcohol use. *Alcoholism, Clinical and Experimental Research*, 33(6), 970–976. https://doi.org/10.1111/j.1530-0277.2009.00917.x

National Institute on Alcohol Abuse and Alcoholism. (2015). *NIAAA Drinking Levels Defined*. https://www.niaaa.nih.gov/alcohol-health/overview-alcohol-consumption/moderate-binge-drinking

Nickerson, A., Barnes, J. B., Creamer, M., Forbes, D., McFarlane, A. C., O'Donnell, M., Silove, D., Steel, Z., & Bryant, R. A. (2014). The temporal relationship between posttraumatic stress disorder and problem alcohol use following traumatic injury. *Journal of Abnormal Psychology*, 123(4), 821–834. https://doi.org/10.1037/a0037920

Nigg, J. T., Wong, M. M., Martel, M. M., Jester, J. M., Puttler, L. I., Glass, J. M., Adams, K. M., Fitzgerald, H. E., & Zucker, R. A. (2006). Poor response inhibition as a predictor of problem drinking and illicit drug use in adolescents at risk for alcoholism and other substance use disorders. *Journal of the American Academy of Child & Adolescent Psychiatry*, 45(4), 468–475. https://doi.org/10.1097/01.chi.0000199028.76452.a9

Noël, X., Brevers, D., & Bechara, A. (2013). A neurocognitive approach to understanding the neurobiology of addiction. *Current Opinion in Neurobiology*, 23(4), 632–638. https://doi.org/10.1016/j.conb.2013.01.018

Norman, S. B., Myers, U. S., Wilkins, K. C., Goldsmith, A. A., Hristova, V., Huang, Z., McCullough, K. C., & Robinson, S. K. (2012). Review of biological mechanisms and pharmacological treatments of comorbid PTSD and substance use disorder. *Neuropharmacology*, 62(2), 542–551. https://doi.org/10.1016/j.neuropharm.2011.04.032

Pavlacic, J. M., Buchanan, E. M., McCaslin, S. E., Schulenberg, S. E., & Young, J. N. (2022). A systematic review of posttraumatic stress and resilience trajectories: Identifying predictors for future treatment of veterans and service members. *Professional Psychology, Research and Practice*, 53(3), 266–275. https://doi.org/10.1037/pro0000451

Pineles, S. L., Mostoufi, S. M., Ready, C. B., Street, A. E., Griffin, M. G., & Resick, P. A. (2011). Trauma reactivity, avoidant coping, and PTSD symptoms: A moderating relationship? *Journal of Abnormal Psychology*, 120(1), 240–246. https://doi.org/10.1037/a0022123

Reynolds, G. M., & Shendruk, A. (2018). *Demographics of the US Military* (Vol. 24). Council on foreign relations.

Riley, E., Mitko, A., Stumps, A., Robinson, M., Milberg, W., McGlinchey, R., Esterman, M., & DeGutis, J. (2019). Clinically significant cognitive dysfunction in OEF/OIF/OND veterans: Prevalence and clinical associations. *Neuropsychology*, 33(4), 534–546. https://doi.org/10.1037/neu0000529

Rose, A. K., & Duka, T. (2008). Effects of alcohol on inhibitory processes. *Behavioural Pharmacology*, 19(4), 284–291. https://doi.org/10.1097/FBP.0b013e328308f1b2

Sadeh, N., Spielberg, J. M., Miller, M. W., Milberg, W. P., Salat, D. H., Amick, M. M., Fortier, C. B., & McGlinchey, R. E. (2015). Neurobiological indicators of disinhibition in posttraumatic stress disorder. *Human Brain Mapping*, 36(8), 3076–3086. https://doi.org/10.1002/hbm.22829

Samuelson, K. W., Newman, J., Abu Amara, D., Qian, M., Li, M., Schultebraucks, K., Purchia, E., Genfi, A., Laska, E., Siegel, C., Hammamieh, R., Gautam, A., Jett, M., & Marmar, C. R. (2020). Predeployment neurocognitive functioning predicts postdeployment posttraumatic stress in Army personnel. *Neuropsychology*, 34(3), 276–287. https://doi.org/10.1037/neu0000603

Schnurr, P. P., & Lunney, C. A. (2016). Symptom benchmarks of improved quality of life in PTSD. *Depression and Anxiety*, 33(3), 247–255. https://doi.org/10.1002/da.22477

Schultebraucks, K., Ben-Zion, Z., Admon, R., Keynan, J. N., Liberzon, I., Hendler, T., & Shalev, A. Y. (2022). Assessment of early neurocognitive functioning increases the accuracy of predicting chronic PTSD risk. *Molecular Psychiatry*, 27(4), 2247–2254. https://doi.org/10.1038/s41380-022-01445-6

Shura, R. D., Rowland, J. A., & Miskey, H. M. (2016). Auditory consonant trigrams: A psychometric update. *Archives of Clinical Neuropsychology*, 31(1), 47–57. https://doi.org/10.1093/arclin/acv083

Simpson, T. L., Stappenbeck, C. A., Luterek, J. A., Lehavot, K., & Kaysen, D. L. (2014). Drinking motives moderate daily relationships between PTSD symptoms and alcohol use. *Journal of Abnormal Psychology*, 123(1), 237–247. https://doi.org/10.1037/a0035193

Skinner, H. A., & Sheu, W. J. (1982). Reliability of alcohol use indices. The Lifetime Drinking History and the MAST. *Journal of Studies on Alcohol*, 43(11), 1157–1170. https://doi.org/10.15288/jsa.1982.43.1157

Sripada, R. K., Pfeiffer, P. N., Rampton, J., Ganoczy, D., Rauch, S. A., Polusny, M. A., & Bohnert, K. M. (2017). Predictors of PTSD symptom change among outpatients in the U.S. Department of Veterans Affairs

Health Care System. *Journal of Traumatic Stress*, *30*(1), 45–53. https://doi.org/10.1002/jts.22156

Strauss, E., Sherman, E. M., & Spreen, O. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary*. American Chemical Society.

Tripp, J. C., Worley, M. J., Straus, E., Angkaw, A. C., Trim, R. S., & Norman, S. B. (2020). Bidirectional relationship of posttraumatic stress disorder (PTSD) symptom severity and alcohol use over the course of integrated treatment. *Psychology of Addictive Behaviors*, *34*(4), 506–511. https://doi.org/10.1037/adb0000564

Vasterling, J. J., & Arditte Hall, K. A. (2018). Neurocognitive and information processing biases in posttraumatic stress disorder. *Current Psychiatry Reports*, *20*(11), Article 99. https://doi.org/10.1007/s11920-018-0964-1

Vogt, D. S., Proctor, S. P., King, D. W., King, L. A., & Vasterling, J. J. (2008). Validation of scales from the Deployment Risk and Resilience Inventory in a sample of Operation Iraqi Freedom veterans. *Assessment*, *15*(4), 391–403. https://doi.org/10.1177/1073191108316030

Weathers, F. W., Keane, T. M., & Davidson, J. R. (2001). Clinician-administered PTSD scale: A review of the first ten years of research. *Depression and Anxiety*, *13*(3), 132–156. https://doi.org/10.1002/da.1029

Wechsler, D. (2001). *Wechsler test of adult reading*. The Psychological Corporation.

Whiteside, S. P., & Lynam, D. R. (2001). The five factor model and impulsivity: Using a structural model of personality to understand impulsivity. *Personality and Individual Differences*, *30*(4), 669–689. https://doi.org/10.1016/S0191-8869(00)00064-7

Wilcox, C. E., Dekonenko, C. J., Mayer, A. R., Bogenschutz, M. P., & Turner, J. A. (2014). Cognitive control in alcohol use disorder: Deficits and clinical relevance. *Reviews in the Neurosciences*, *25*(1), 1–24. https://doi.org/10.1515/revneuro-2013-0054

Woods, S. P., Delis, D. C., Scott, J. C., Kramer, J. H., & Holdnack, J. A. (2006). The California Verbal Learning Test—Second edition: Test–retest reliability, practice effects, and reliable change indices for the standard and alternate forms. *Archives of Clinical Neuropsychology*, *21*(5), 413–420. https://doi.org/10.1016/j.acn.2006.06.002

Zandberg, L. J., Rosenfield, D., Alpert, E., McLean, C. P., & Foa, E. B. (2016). Predictors of dropout in concurrent treatment of posttraumatic stress disorder and alcohol dependence: Rate of improvement matters. *Behaviour Research and Therapy*, *80*, 1–9. https://doi.org/10.1016/j.brat.2016.02.005

Zang, Y., Su, Y. J., McLean, C. P., & Foa, E. B. (2019). Predictors for excellent versus partial response to prolonged exposure therapy: Who needs additional sessions? *Journal of Traumatic Stress*, *32*(4), 577–585. https://doi.org/10.1002/jts.22412

Zatzick, D. F., Grossman, D. C., Russo, J., Pynoos, R., Berliner, L., Jurkovich, G., Sabin, J. A., Katon, W., Ghesquiere, A., McCauley, E., & Rivara, F. P. (2006). Predicting posttraumatic stress symptoms longitudinally in a representative sample of hospitalized injured adolescents. *Journal of the American Academy of Child & Adolescent Psychiatry*, *45*(10), 1188–1195. https://doi.org/10.1097/01.chi.0000231975.21096.45

Zatzick, D. F., Kang, S. M., Müller, H. G., Russo, J. E., Rivara, F. P., Katon, W., Jurkovich, G. J., & Roy-Byrne, P. (2002). Predicting posttraumatic distress in hospitalized trauma survivors with acute injuries. *The American Journal of Psychiatry*, *159*(6), 941–946. https://doi.org/10.1176/appi.ajp.159.6.941

Zoellner, L. A., Roy-Byrne, P. P., Mavissakalian, M., & Feeny, N. C. (2019). Doubly randomized preference trial of prolonged exposure versus sertraline for treatment of PTSD. *The American Journal of Psychiatry*, *176*(4), 287–296. https://doi.org/10.1176/appi.ajp.2018.17090995