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Traumatic Brain Injury and Suicidal Thoughts and Behaviors among Post-9/11 Veterans: Investigating Longitudinal Change and Interactions with Mental Health

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ABSTRACT

Veterans die by suicide at almost twice the rate of non-veterans, and risks for suicide can be further increased after sustaining traumatic brain injury (TBI). This is notable, given that over 20 % of post-9/11 Veterans are estimated to have experienced TBI. Better understanding risk for suicidal thoughts and behaviors (STBs) would allow for improved screening processes and targeted treatment approaches. In this study, we use data from 823 veterans who served after September 11, 2001 and participated in the VISN 6 MIRECC's Post-Deployment Mental Health Study. In total, 511 (62.1 %) veterans reported at least one TBI during their lifetime and 241 (29.3 %) reporting at least one TBI during military deployment. Veterans had more STBs at baseline if they also reported more lifetime TBIs ($\beta = 0.45$, CI [0.18, 0.72], $p < .001$) or deployment TBI ($\beta = 0.53$, CI [0.16, 0.90], $p = .005$). When examining change over 12 years, veterans showed greater increases in STBs if they reported more lifetime TBIs ($\beta = 0.34$, CI [0.12, 0.55], $p = .002$) or deployment TBI ($\beta = 0.62$, CI [0.33, 0.91], $p < .001$). These associations remained when accounting for baseline mental health conditions (depressive symptoms, posttraumatic stress disorder symptoms, and lifetime trauma burden). All reported results accounted for age, gender, self-reported race/ethnic group, and education. Findings suggest that TBI is associated with increases in STBs and emergence of STBs over time. To better differentiate risk, screening measures and treatment for STBs should consider whether brain injury occurred in combat.

1. Introduction

The rate of suicide among veterans is roughly double that of the general population, at 32 per 100,000, compared to 17.2 per 100,000 non-veterans (Ramchand, 2022). Traumatic brain injury (TBI) is considered a signature wound of the post-9/11 era (Howard et al., 2022; Lindquist et al., 2017), and is associated with poor mental health outcomes and increased risk of suicidal thoughts and behaviors (STBs; Campbell-Sills et al., 2021; Fonda et al., 2017; Ineson et al., 2023; King and Wray, 2012; Levin et al., 2013; Wisco et al., 2014). TBI appears to compound suicide risk in veterans: those who experience TBI are 1.5 times more likely to die by suicide than veterans without TBI (Madsen et al., 2018; Ramchand, 2022; Wisco et al., 2014). This is particularly concerning given the prevalence of TBI in post-9/11 veterans—more than 20 % of this cohort is estimated to have experienced a TBI (Howard et al., 2022). Identifying who is most at risk of developing STBs through examining associations between TBI and suicide related outcomes has the potential to inform more effective prevention strategies, improve the delivery of evidence-based care, and save veteran lives.

TBI occurs as the result of an external force to the skull, resulting in neuronal cell death, edema, and both axonal and vascular damage (Department of Defense, 2023; Zetterberg et al., 2013). TBI is categorized as mild, moderate, or severe, based on clinical parameters (Malec et al., 2007). In post-9/11 veterans who were deployed during

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Operation Iraqi Freedom, Operation Enduring Freedom, or Operation New Dawn (OIF/OEF/OND), blast injury accounted for the majority of TBIs sustained during deployment (Bell et al., 2009). However, TBI is common in the veteran population broadly, with one study finding that only ~25% of veterans seeking care for TBI had served in a combat zone (Dismuke et al., 2015). The study did not distinguish between those who sustained a TBI during deployment and those who did not, suggesting the number of those who were injured during deployment is likely even lower. Although >80% of TBI falls into the mild category (Department of Defense, 2023), TBI of all severities are associated with neurobehavioral and neuropsychological sequelae and elevated suicide risk (Azouvi et al., 2017; Levin et al., 2013).

The ways that TBI might contribute to suicide risk are multifactorial and an area of active study. A comprehensive study by Brenner and colleagues (2023) demonstrated that history of TBI increased risk of developing co-morbid psychiatric conditions, such as anxiety, post-traumatic stress disorder (PTSD), and substance use disorders. Direct effects of the injury on frontal circuits can increase impulsivity, aggression, and poor decision-making (Aaronson et al., 2024; Lu et al., 2020). Individuals with TBI can be prone to disinhibition and disruptions to executive functioning (Azouvi et al., 2017; Howlett et al., 2022; Rabinowitz and Levin 2014). These injuries are also associated with sleep disturbances and insomnia, which are independent risk factors for suicide (McCall and Black, 2013). TBI is often associated with chronic pain, which may increase suicide risk, particularly when co-morbid with PTSD (Blakey et al., 2018). Additionally, TBI increases risk of functional or social impairments (Eslinger et al., 1995; Ramanathan-Elion et al., 2020; Torregrossa, 2023). Thus, TBI could increase risk for suicide directly through disruption of neural circuits and direct damage to the brain, or indirectly by increasing vulnerability to related mental health conditions (Brenner et al., 2023; Lu et al., 2020).

The demographics of the most recent cohorts of veterans are changing, including more women and non-white veterans (Schaeffer, 2023). There is a pressing need to understand whether gender and racial demographics may influence risk of developing STBs after TBI. Some studies suggest that women veterans have worse neuropsychological sequelae, including more post-concussive symptoms, worse PTSD symptoms, and increased utilization of outpatient services than men veterans (Brickell et al., 2017; Cogan et al., 2020; McGlade et al., 2015). Conversely, men veterans with TBI were more likely to engage in problematic alcohol use than women veterans (Grossbard et al., 2017; Miles et al., 2015 Sayko Adams et al., 2017). One study by Forslund et al. reported that male gender predicted better trajectories 5–10 years after sustaining a TBI, though few studies examine TBI outcomes beyond 10 years (Forslund et al. 2019). However, many studies do not consistently report on gender differences for STBs. To our knowledge, there are no studies that examine gender differences in how STBs evolve over time greater than 10 years after sustaining a TBI in veterans.

There are also some data to support that race and ethnicity may also be a predictor of suicidal thoughts: One study found that white race and ethnicity was a predictor of suicidal thoughts in individuals with TBI who also had PTSD and chronic pain (Blakey et al., 2018). However, such studies are complicated by underreporting of symptoms in racial and ethnic groups that may experience cultural stigma around STBs: A civilian study demonstrated Black and Hispanic individuals were less likely to report suicidal thoughts but more likely to report a suicide attempt in the previous year (Bommersbach et al., 2023). Studies in the civilian population demonstrate racial and ethnic group disparities in outcomes after sustaining TBI, with Black and Hispanic individuals showing poorer functional independence and employment outcomes (Shafi et al., 2007; Arango-Lasprilla et al., 2011; Jamison et al., 2012). In veterans, these racial and ethnic groups are also less likely to utilize Veteran's Affairs (VA) services (C. E. Dismuke et al., 2015). The increased loss of independence and functionality and lower use of services, combined with cultural stigma around STBs, may result in underreporting of symptoms while conferring increased risk. How risk may evolve differentially between ethnic groups over the long term remains unknown. Further research is needed to broaden our understanding of how gender and ethnic group differences may contribute to risk of developing STBs.

To date, there are few prospective studies that show the emergence of STBs over time in veterans with TBI. It is unclear whether risk of STBs remains static or evolves over time. Although studies demonstrate that impulsivity and co-morbid psychiatric conditions mediate the relationship between TBI and STBs, the role of baseline mental health characteristics, such as psychological distress, depressive symptoms, or trauma history, on emergence of STBs remains unclear (Aaronson et al., 2024; Brenner et al., 2023). Additionally, context may influence risk. One study demonstrated that active duty service members who sustain TBIs while in combat have more depressive- and PTSD-related symptoms than those who sustained a TBI prior to deployment (Remigio-Baker et al., 2023). Another study demonstrates deployment-related TBIs are associated with new-onset mental health conditions and confer increased suicide risk (Brenner et al., 2023). How deployment-related TBI may influence emergence of STBs longitudinally, however, is unknown. The present study aimed to address these gaps using data from a prospective cohort of veterans to evaluate changes in STBs over a 12-year period. Understanding how TBI may contribute to long-term risk of STBs, as well as moderating factors such as baseline mental health characteristics, could help improve screening measures and clarify individuals most at risk for STBs who might benefit from targeted interventions.

1.1. Present study

In this study, we use data from 823 U.S. military veterans (Brancu et al., 2017) who served in the period following September 11, 2001. Participants had mental health characteristics and TBI history assessed at baseline and a follow-up approximately 12 years later. To our knowledge, this is the first study to prospectively study emergence of STBs in veterans with TBI over a long-term follow up. We tested the association of TBI (deployment- and non-deployment) with STBs at baseline and follow-up, allowing us to assess change in STBs over 12 years. We evaluated baseline mental health characteristics, lifetime trauma burden, and demographic characteristics as moderators of risk of emergence of STBs. We hypothesized that higher levels of baseline mental health concerns and prior trauma history would moderate associations between TBI and STBs at follow-up, with higher levels of baseline mental health concerns and reported trauma history increasing the strength of these associations. We also hypothesized that deployment-related TBI would show stronger associations with STBs compared to non-deployment-related TBI. Finally, we also conducted secondary analyses to examine whether men and women veterans would show different associations between TBI and STBs, as well as whether they might be differences between non-Hispanic Black and non-Hispanic White veterans.

2. Methods

2.1. Participants

Participants were members of the Veterans Integrated Service Networks (VISN) 6 Mental Illness Research, Education and Clinical Center (MIRECC)'s Post-Deployment Mental Health (PDMH) study, a multi-site study of U.S. veterans deployed in the post-9/11 period (Brancu et al., 2017). The VA Mid-Atlantic MIRECC began the PDMH data collection in 2005 as a regional cohort data repository for the purpose of understanding the mental health and treatment needs of millions of veterans returning from post-9/11 deployments. Data collection for the follow-up is ongoing with participants completing the second visit approximately 12 years later (PDMH-L). All participants provided written informed consent to participate in procedures approved by the Institutional

Review Board at the participating sites (Durham NC, Salisbury NC, and Richmond Veterans Affairs (VA) Healthcare Systems). Our study included participants who completed the follow-up assessment, resulting in an analytic sample of 823 veterans.

2.2. Measures

2.2.1. Traumatic brain injury

TBI history was evaluated using the Mid-Atlantic MIRECC Assessment of Traumatic Brain Injury (MMAT-TBI; Brancu et al., 2017; Rowland et al., 2020). This validated (Rowland et al., 2020) semi-structured interview first screens for any potential concussive events. Potential concussive events are further evaluated, including both a narrative description and clinical indicators of TBI, e.g. loss or alterations of consciousness and post-traumatic amnesia. Method of injuries were assessed (blunt force, blast, penetrating, acceleration-deceleration, or other). All events were evaluated for mechanism and context (e.g. deployment or non-deployment). The assessment includes a questionnaire of post-concussive symptoms. Additionally, timing of all events was used to determine whether injury occurred prior to or after baseline assessment. These responses were used to construct measures of total lifetime TBI count and deployment TBI count with three categories (0 = no TBI, 1 = 1 TBI, 2 = 2+ TBIs). Additional measures included whether veterans experienced a TBI between the baseline and follow up assessment, as well as the experience of blast TBI and moderate to severe TBI. Mild TBI is defined as a loss of consciousness of less than 30 min, with post-traumatic amnesia or confusion lasting less than 24 hours. Individuals who reported symptoms that exceed these parameters were classified as moderate to severe TBI.

2.2.2. Post-traumatic stress disorder (PTSD) symptoms

PTSD symptoms were assessed using the Davidson Trauma Scale (DTS; Davidson et al., 2002). This scale consists of 17 self-report measures using a 5-point Likert-scale for frequency and intensity of symptoms, with higher scores corresponding to greater PTSD symptoms. The mean score for PTSD symptoms was 38.93 (standard deviation of 39.1).

2.2.3. Depressive symptoms

Depression was assessed using the Beck Depression Inventory-II (BDI; Storch et al., 2004). The BDI is a 21-item questionnaire using a 0 to 3-point Likert-scale for intensity of depressive symptoms. Responses were summed with higher scores corresponding to greater depression symptoms. The mean score for the BDI was 13.72 (standard deviation of 12.0).

2.2.4. Trauma history

Childhood and adult trauma history were assessed using the Trauma Life Experiences Questionnaire (TLEQ; Kubarny et al., 2000). The TLEQ consists of 22 items describing potential traumatic events, and a 23rd "other events" category. Trauma burden was assessed using the total number of categories of trauma endorsed by veterans. The mean score for the TLEQ was 6.28 (standard deviation of 3.7).

2.2.5. Suicidal thoughts and behaviors (STBs)

STBs were assessed using the Beck Scale for Suicide Ideation (BSS; Beck et al., 1997). Values for 19 self-report items (scored from 0–2) were summed such that higher scores indicate more severe levels of STBs. We evaluated both a total score and a dichotomized measure for the purpose of visualization. The dichotomized score was created to represent for presence or absence of STBs, where individuals with any scores above 0 on the BSS were given a score of 1, whereas all other veterans received a score of 0. The mean score at baseline was 1.05 (standard deviation of 3.2). The mean score at follow-up was 0.78 (standard deviation of 2.5). At baseline, 54 veterans (6.6 % of the sample) reported having a suicide attempt in the past. Prior suicide attempts were evaluated using item 20 on the BSS. Overall, skewness was 3.8 at baseline and 4.2 at follow-up. Kurtosis was 16.8 at baseline and 19.5 at follow-up.

2.3. Data analysis

We tested the association of TBI with STBs in a series of multiple regression models. We first assessed the association of TBI—both over the lifetime and during military deployment—with STBs at the baseline assessment, then with change in STBs from the PDMH baseline to PDMH-L assessment approximately 12 years later. Models assessing change included baseline levels of STBs to create residualized change models. We then specified additional models to assess the association between TBI and STBs when accounting for baseline mental health symptoms and diagnoses, moderating by baseline mental health symptoms and diagnoses, when stratifying by self-reported gender, self-reported race and ethnic group, and when accounting for TBI severity, TBI due to blast exposure, and TBI timing. Finally, we conducted an additional sensitivity analysis using a dichotomized measure of STBs (present or absent) to provide additional context to our main findings and for models that could account for positive skew present in the STBs measures. All models were run in MPLUS version 8.3 (Muthen and Muthen, 2012) using full maximum likelihood estimation to account for missing data and controlled for demographic covariates (age, gender, race and ethnic group, education, and time between PDMH assessments). Notably, missingness was less than 1 % for all primary study variables (1 missing value for BSS at baseline, 6 missing values for PTSD symptoms and race/ethnic group, and 7 missing values for education, all other primary study variables had full data). Given the limited extent of missingness (<1 % across all variables), we elected to use Full Information Maximum Likelihood (FIML) to handle massing data (Graham, Cumsille, and Shevock, 2012). Reported βs reflect standardized effect sizes between TBI count categories and *SD* change in BSS scores.

3. Results

The 823 veterans were comprised of 650 men (79.0 %) and 173 women (21.0 %), and included 51.8 % non-Hispanic Black veterans, 45.7 % non-Hispanic White veterans, with the remaining veterans reporting another race or ethnic group (Table 1). At baseline, veteran average age was 38.8 (*SD* = 10.1) with an average 11.9 years (*SD* = 0.6) to PDMH-L follow up. The majority of veterans (62.1 %) reported at least one TBI during their lifetime, with 241 (29.3 %) reporting at least one TBI during military deployment, and 55 (6.7 %) reporting a TBI with symptoms consistent with moderate TBI severity. At baseline, 134 veterans reported STBs (16.3 %), with a descriptively higher rate among veterans with a TBI (19.8 %) compared to those without a TBI (10.6 %). 134 veterans also reported STBs at follow up (16.3 %), and the rate of STBs was roughly twice as high among veterans with a TBI (20.5 %) compared to those without a TBI (9.3 %). We considered gender and race/ethnic group as covariates in all regression analyses to account for their potential influence on the relationship between TBI and STBs. We additionally stratified by these groups to examine whether the strength

Table 1
Demographic characteristics of PDMH participants.

Demographics	*N*	%	Mean	SD
Gender				
Men	650	79.0		
Women	173	21.0		
Race/Ethnic group				
Non-Hispanic Black	426	51.8		
Non-Hispanic White	376	45.7		
Another race/ethnicity group*	21	2.5		
Average age			38.8	10.1
Time to follow-up			11.9	0.6

* The remaining participants were largely comprised of Asian and Hispanic veterans.

of the association between TBI and STBs differed by gender or race/ethnic group.

3.1. TBI and baseline suicidal thoughts and behaviors (STBs)

Veterans reporting more lifetime TBIs were associated with STBs at baseline (β = 0.45, 95 % CI [0.18, 0.72], $p < .001$). Veterans reporting TBIs during military deployment were also associated with STBs at baseline (β = 0.53, 95 % CI [0.16, 0.90], $p = .005$).

3.2. TBI and change in STBs over 12 years

Using the continuous BSS scale, we examined how STBs changed over time. Veterans reporting more lifetime TBIs had greater increases in STBs over the 12-year follow up (β = 0.34, 95 % CI [0.12, 0.55], $p = .002$). TBIs during deployment were also associated with increased STBs (β = 0.62, 95 % CI [0.33, 0.91], $p < .001$).

3.3. Accounting for baseline mental health

We next examined whether TBI remained associated with increases in STBs when accounting for baseline mental health characteristics. Both lifetime and deployment TBIs remained associated with increases in STBs over the following 12 years when accounting for PTSD, depression, or trauma exposure (Table 2). When examining main effects for the baseline mental health characteristics, PTSD symptoms (β = 0.23, 95 % CI [0.04, 0.41], $p = .017$) and depressive symptoms (β = 0.34, 95 % CI [0.15, 0.53], $p < .001$) were independently associated with change in STBs, as might be expected given overlap in the experience of STBs and these mental health conditions, particularly depression (which includes suicidal ideation as an indicator). In contrast, trauma exposure did not show a significant association, (β = 0.13, 95 % CI [−0.04, 0.31], $p = .135$).

Table 2
Associations between TBI and change in STBs over 12 years.

Outcome: Change in suicidal thoughts and behaviors (STBs)		
$N = 823$	β	95 % CI
Overall associations		
Lifetime TBI	0.34**	[0.12, 0.55]
Deployment TBI	0.62**	[0.33, 0.91]
Accounting for PTSD symptoms		
Lifetime TBI	0.29**	[0.07, 0.51]
Deployment TBI	0.56**	[0.26, 0.87]
Accounting for depressive symptoms		
Lifetime TBI	0.27*	[0.05, 0.49]
Deployment TBI	0.52**	[0.22, 0.82]
Accounting for trauma exposure		
Lifetime TBI	0.32**	[0.09, 0.54]
Deployment TBI	0.60**	[0.30, 0.90]
Moderating by baseline mental health		
Lifetime TBI × PTSD symptoms	0.08	[−0.13, 0.29]
Lifetime TBI × Depressive symptoms	0.16	[−0.05, 0.37]
Lifetime TBI × Trauma exposure	0.04	[−0.18, 0.25]
Deployment TBI × PTSD symptoms	−0.08	[−0.36, 0.20]
Deployment TBI × Depressive symptoms	−0.11	[−0.38, 0.17]
Deployment TBI × Trauma exposure	−0.12	[−0.41, 0.17]
Stratifying by gender		
Lifetime TBI, men veterans	0.34**	[0.10, 0.58]
Lifetime TBI, women veterans	0.30	[−0.19, 0.79]
Deployment TBI, men veterans	0.66**	[0.35, 0.97]
Deployment TBI, women veterans	0.23	[−0.61, 1.06]
Stratifying by race and ethnic group		
Lifetime TBI, non-Hispanic Black veterans	0.28*	[0.01, 0.55]
Lifetime TBI, non-Hispanic White veterans	0.22	[−0.11, 0.56]
Deployment TBI, non-Hispanic Black veterans	0.32	[−0.08, 0.71]
Deployment TBI, non-Hispanic White veterans	0.66**	[0.24, 1.08]

Note: All models controlled for demographic (age, gender, race and ethnic group, and education) and technical covariates (chip type, white blood cell type proportions). CI = confidence interval.
* $p < .05$.
** $p < .01$.

3.4. Moderating associations by mental health characteristics

We then tested whether baseline mental health characteristics might moderate the association between TBI and increases in STBs by examining interactions between both baseline mental health characteristics (PTSD symptoms, depression symptoms, and trauma exposure) as well as baseline psychiatric diagnoses of depression and PTSD with TBI. The rate of clinical depression diagnosis in those who had deployment-related TBI was 26.8 %, compared to 12.2 % of non-deployment-related TBI. The rate of clinical PTSD diagnosis for deployment-related TBI was 46.5 %, compared to 19.4 % of non-deployment-related TBI. However, when controlling for PTSD and depression, neither PTSD symptoms, depression symptoms, nor trauma exposure significantly moderated the association between TBI and change in STBs (Table 2). When examining main effects and moderations of baseline clinical diagnoses (MDD and PTSD), the substantive results were unchanged—lifetime and deployment TBIs remained associated with change in STBs and neither diagnosis moderated the association of TBIs and change in STBs.

3.5. Stratifying results by gender, and by race and ethnic group

We next examined the association between TBI and increases in STB when stratified by gender (men veterans, $n = 630$; women veterans, $n = 166$), then by race and ethnic group for the two major racial and ethnic groups comprising the sample (non-Hispanic Black veterans, $n = 426$; non-Hispanic White veterans, $n = 373$). As shown in Table 2, the size of associations was relatively similar among men and women veterans, as well as non-Hispanic Black and non-Hispanic White veterans. When conducting formal tests for moderation for lifetime TBI, associations were not significantly moderated by either gender (β = −0.06, 95 % CI [−0.60, 0.48], $p = .832$) or race and ethnic group (β = 0.02, 95 % CI [−0.39, 0.43], $p = .932$). Simialrly, none of the association were significantly moderated by either gender (β = −0.34, 95 % CI [−1.25, 0.57], $p = .331$) or race and ethnic group for deployment TBI (β = −0.11, 95 % CI [−0.68, 0.46], $p = .712$).

3.6. Sensitivity analysis: investigating the role of TBI severity

The assessment of TBI included reported length of loss of consciousness, post-concussive amnesia, and post-concussive confusion, that enabled us to categorize TBIs reaching criteria for a moderate level of severity (or greater) based on established clinical criteria of TBI severity. Veterans experiencing a moderate TBI ($n = 55$, 6.7 %) did not show greater increases in STBs over the 12-year follow up beyond the variance accounted for by total lifetime TBIs (β = 0.35, 95 % CI [−0.34, 1.05], $p = .320$).

3.7. Sensitivity analysis: investigating the role of TBI due to blast

The assessment of TBI included reported whether the injury was due to blast exposure, with 147 (18.5 %) veterans reporting one TBI due to blast and 33 (4.1 %) reporting two or more TBIs due to blast. Blast TBI was associated with increases in STBs over the 12-year follow up (β = 0.73, 95 % CI [0.40, 1.06], $p < .001$). This association was similar in magnitude to deployment TBIs, with a somewhat larger confidence interval given the smaller number of blast TBIs.

3.8. Sensitivity analysis: investigating the role of TBI timing

Due to the timing of the TBI assessment, there were a subset of 124 veterans (15.1 %) who experienced a TBI between the baseline and 12-year follow up assessments. Veterans who experienced a TBI between

occasions did not evidence significantly greater increases in their STBs (β = 0.13, 95 % CI [−0.34, 0.61], p = .583), including when adjusting for amount of lifetime TBIs at baseline (β = 0.15, 95 % CI [−0.32, 0.63], p = .530).

3.9. Sensitivity analysis: examining new onset of suicidal thoughts and behaviors (STBs)

To provide a measure of simplified measure that could be used to assess new onset STBs, we dichotomized the BSS to represent veterans with and without the presence of STBs at baseline and follow up. As shown in Fig. 1, when including only veterans without STBs at baseline (n = 689), 7.9 % of veterans without a lifetime TBI reported STBs at the follow up, compared to 11.1 % for veterans with 1 TBI and 19.2 % for veterans with 2 or more TBIs.

Veterans with 2 or more TBIs were 2.4 times more likely to go report STBs at the follow up compared to veterans with no reported lifetime TBI. When examining the proportion of veterans who reported STBs at both occasions, 2.3 % of the veterans without any lifetime TBIs reported STBs at both occasions, compared to 8.1 % of veterans with 1 TBI and 8.7 % of veterans with 2+ TBIs. Said differently, having a TBI resulted in a fourfold risk for veterans to report STBs at the two study assessments 12 years apart, representing about 6 % absolute increase in risk. These broad patterns were replicated when examining TBIs during military deployment.

4. Discussion

Among 823 post-9/11 Veterans, we found that veterans with more lifetime TBIs and deployment TBIs at baseline were at greater risk of increased levels of STBs over a 12-year follow-up. Moderate (or greater) severity TBI did not show greater increases in emergence of STBs compared to mild TBI. Risk of increased STBs at long-term follow-up remained when accounting for baseline levels of depression, PTSD, and history of childhood trauma. These results suggest that TBI confers risk beyond that explained by psychopathology and highlights the importance of assessing TBI history and longitudinal changes in STBs.

This study complements other studies that examine baseline psychological characteristics and risk of developing STBs. A TRACK-TBI study by Campbell-Sills and colleagues (2021) found that preexisting psychiatric history increased risk of suicidal ideation following injury at 2 weeks and 6 months following TBI. Our study similarly found that baseline clinical diagnoses of depression (β = 0.34) and PTSD (β = 0.23) were independently associated with the emergence of STBs in long-term follow-up (although trauma history alone was not). In contrast, our study found that TBI status at baseline was an independent risk factor for increases in STBs over a 12-year follow-up, and the association between TBI and STBs is not statistically influenced by baseline psychiatric diagnoses or trauma history.

Two key differences between these studies are worth highlighting. Campbell-Sills and colleagues (2021) assessed the emergence of suicidal ideation in the short-term aftermath of TBI, whereas our study examined increases of suicidal ideation many years after TBI. This suggests that baseline psychological characteristics may contribute to risk of STB following TBI in the short-term, but may be less relevant in the long-term. This hypothesis is further supported by the result that TBI occurring between the first and second study visits were not associated with emergence of STBs at follow-up. Second, the study by Campbell-Stills and colleagues was in a non-veteran population. It is possible that baseline psychological characteristics are less relevant in the veteran population or there is a particularly relevant of TBI experiences as part of military deployment, and future studies should empirically test these possibilities longitudinally. To our knowledge, there are no similar longitudinal studies in the non-veteran population that would address the question as to whether baseline psychological characteristics have long-term relevance to change in STBs over this long a follow up among non-veterans.

The mechanism by which TBI appears to increase risk of STBs in the long-term in the post-9/11 cohort of veterans is unclear. One possible hypothesis could relate to structural changes to the brain: even mild TBI shows reduced brain volume in certain regions after injury (Kim et al., 2021). Another study by Yurgelun-Todd et al. found diminished activity in brain regions that are crucial for impulse control and emotional regulation in veterans with TBI (Yurgelun-Todd et. al., 2011). Whether these structural changes may impact neural circuitry or increase risk of degenerative processes is unknown, but their presence warrants further investigation using functional neuroimaging and cognitive evaluation. Additionally, TBI increases risk of developing comorbid psychiatric illness, which may contribute to risk: a large cohort study by Brenner and colleagues (2023) found that history of TBI dramatically increased

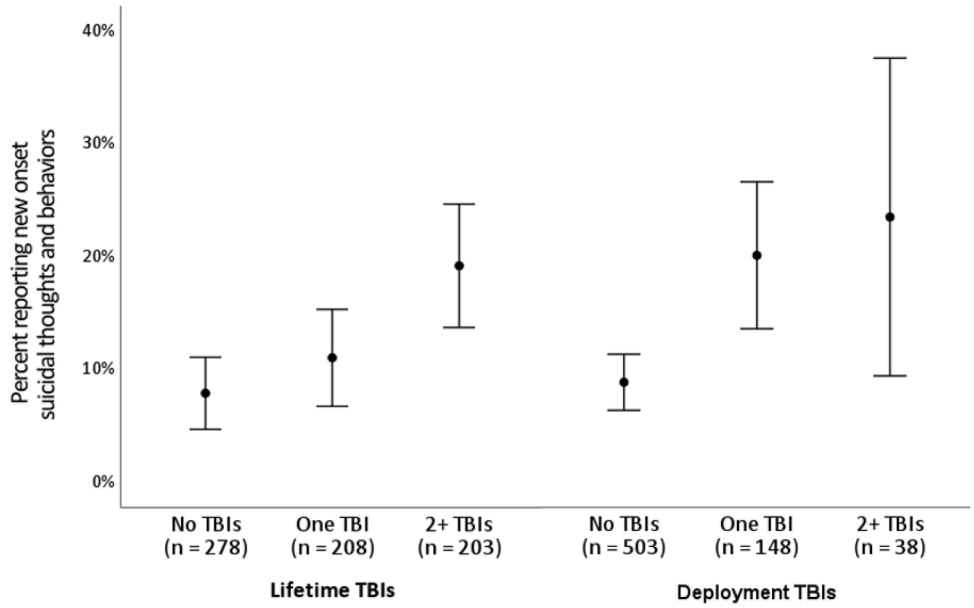

Fig. 1. Proportion of veterans with new onset STBs at the 12-year follow up based on number of lifetime and deployment TBIs. Error bars represent 95 % confidence intervals.

risk of PTSD, depression, and especially substance use disorders. This study concluded that TBI influences suicide rate both directly (as a result of the injury) and indirectly (by increasing vulnerability to developing new-onset mental health disorders that increase risk). Our study found an independent association between TBI and STBs, however it is possible that the increased vulnerability to other psychopathologies may contribute to increased rates of STBs in this population. Additionally, TBI-related disability can also result in functional deficits that increase risk of STBs due to psychological reactions to new impairments, disruptions to social relationships and occupational functioning, and changes in self-concept (Mascialino et al. 2022; Simpson and Tate 2002). Finally, it is also possible that unique characteristics of the veteran population increase vulnerability to emergence of STBs. However, the lack of similar studies in non-veteran populations makes this hypothesis difficult to evaluate.

Compared to TBI sustained outside military service, we found that deployment-related TBI carried relatively greater risk for STBs ($\beta = 0.62$ for deployment TBI, compared to $\beta = 0.34$ for lifetime). One possible explanation may be the nature of the injury: TBI sustained in the military is most commonly due to blast injury, a form of injury that is unusual outside of the military (Bell et al., 2009; Karr et al., 2019). Blast injury is associated with worse post-concussive symptoms, which may increase risk of comorbid psychiatric disorders or the emergence of STBs (Dickstein et al., 2021). Blast exposed-veterans have also demonstrated increased cortical thinning compared to veterans with TBI but without blast exposure, suggesting blast exposure may have influences that are unrelated to TBI (Clark et al., 2018). Cumulative blast exposure is also shown to worsen recovery from TBI, which may further increase risk for STBs (Bailie et al., 2024). In this sample, 43.8 % of veterans had blast injuries. The effect sizes for those with blast injuries and those with deployment-related TBI were similar, suggesting that blast injury may partially account for the increased risk of STBs in those with deployment-related TBI. These data further support the importance of assessing for STBs in veterans with a history of blast injury.

We found that non-Hispanic White veterans showed a descriptively stronger association between TBI and increased STB compared to non-Hispanic Black veterans ($\beta = 0.66$ for non-Hispanic White veterans compared to $\beta = 0.32$ for non-Hispanic Black veterans), though the formal interaction was non-significant, possibly due to power limitations. No significant results were seen in women veterans or non-Hispanic Black veterans, though both groups demonstrated similar trends. This lack of findings may be due to cultural differences and limitations of methodology and sample size. The reliance on self-reported data may result in underreporting of symptoms, particularly in minority ethnic groups (Bommersbach et al., 2023). Future studies would benefit from greater representation of gender, race and ethnic group with larger sample sizes to detect differences between TBI and subsequent STBs. Our results are consistent with a growing body of evidence finding that multiple TBIs increases risk of suicidal ideation (Bryan and Clemans, 2013; Shura et al., 2019) and supplements these existing data by demonstrating the importance of TBI history regardless of psychiatric status and history.

4.1. Strengths

This study has notable strengths. To our knowledge, it is the first study to examine the emergence of STBs in veterans with TBI over a 12-year follow-up. It is consistent with prior studies that suggest multiple injuries and deployment-related TBIs worsen outcomes (Bryan et al., 2013; Campbell-Sills et al., 2020; Pugh et al., 2019; Sayko Adams et al., 2017; Shura et al., 2019; Stanley et al., 2017) and builds on these findings, finding that TBI is a risk factor for increases in STBs over a 12-year follow-up. Baseline TBI status was found to be independently associated with new onset STBs: baseline psychiatric diagnoses did not account for or modify this association. This study is also more representative of the changing demographics of the younger cohorts of veteran population as it included a substantial number of non-White and women participants.

4.2. Limitations

The results of this study should be interpreted within the context of several limitations. First, low rates of suicidal ideation and TBI could have reduced statistical power and may limit our ability to detect modifiers with smaller associations. Although there were over 800 veterans in the total sample, the number of women and specifically women with TBI was smaller ($n = 73$), leading to wide confidence intervals and lack of significance in smaller subgroups. Future studies would benefit from using larger samples to improve power. Second, this study relied on self-report measures; therefore it is possible that symptoms are under- or over-reported in certain subpopulations. Similarly, some of these measures have not been validated specifically for use in populations of veterans with TBI. Third, TBIs were assessed using retrospective reports, which can further limit the accuracy of reported data and the possible misclassification of TBI severity. Fourth, this study sampled veterans from the mid-Atlantic region and thus may not generalize to other regions. Fifth, although STB is a risk factor for suicide, not all individuals who complete suicide had preexisting STBs (Coon et al., 2024). Suicide is a rare event and our study was not powered to establish a clear connection between emergence of STBs and completed suicide. Sixth, it is outside the scope of this study to evaluate how management of mental health might be associated with TBI characteristics. Future studies would benefit from more deeply exploring how utilization of mental health care may influence emergence of STBs. Such a study would be especially important given that underutilization of mental health services, a particular problem in minority ethnic groups, may confer increased risk of STBs. Seventh, this study did not examine years of active duty, which may impact lifetime TBI and mental health outcomes. Finally, two occasions of STB measurement limited our ability use more sophisticated analytic models to examine the timing of STBs, TBI, and mental health symptoms.

4.3. Conclusions

As the post-9/11 cohort ages, it is important to consider how deployment and deployment-related injuries might contribute to the development of STBs. These data support the need for assessing STBs in veterans with a history of TBI, even if they did not have prior history of STBs or psychiatric illness. Future studies would benefit from examining the correlations between structural changes to the brain and risk of STBs, establishing a timeline of STBs and psychiatric disorders, and a larger cohort, particularly in women veterans, to better clarify gender differences in risk of developing STBs. Nonetheless, this study provides important evidence that multiple TBIs, particularly during deployment, were associated with the long-term emergence of STBs.

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Conflicts of interest

No authors have conflicts of interest to report.

Data sharing statement

Data from the Post Deployment Mental Health (PDMH) Study are available to researchers who request access through the VISN 6 MIRECC and follow the appropriate data access protocols. Medical record data from the Veteran Affairs Corporate Data Warehouse are available to researchers who request and are approved for access through the Office of Research and Development (ORD) Data Access Request Tracker (DART).

CRediT authorship contribution statement

Alyssa Bernanke: Writing – original draft, Conceptualization. **Nathan A. Kimbrel:** Writing – review & editing, Investigation, Funding acquisition. **Jean C. Beckham:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Kyle J. Bourassa:** Writing – review & editing, Supervision, Formal analysis, Conceptualization.

Declaration of competing interest

The authors have no outside interests to declare.

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