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Effects of blast exposure on psychiatric and health symptoms in combat veterans

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ABSTRACT

Blast exposure is common among service members, but the chronic psychiatric effects associated with blast exposure are not well-characterized independent of a resulting mild traumatic brain injury (TBI). This analysis evaluated whether blast exposure severity was independently associated with or exacerbated symptom report beyond posttraumatic stress disorder (PTSD) and mild TBI. Participants were Iraq and Afghanistan combat veterans ($N = 275$; 86.55% male), 71.27% with history of blast exposure, 29.82% current diagnosis of PTSD, and 45.45% with mild TBI. All participants completed diagnostic interviews for PTSD, lifetime TBI, and lifetime blast exposure. Self-reported psychiatric and health outcomes included posttraumatic stress symptoms, depressive symptoms, neurobehavioral symptoms, sleep quality, pain interference, and quality of life. Blast severity was associated with PTSD ($B = 2.00$), depressive ($B = 0.76$), and neurobehavioral ($B = 1.69$) symptoms beyond PTSD diagnosis and mild TBI history. Further, blast severity accounted entirely (i.e., indirect/mediation effect) for the association between TBI and posttraumatic stress ($B = 1.62$), depressive ($B = 0.61$), and neurobehavioral ($B = 1.38$) symptoms. No interaction effects were present. Exposure to blast is an independent factor influencing psychiatric symptoms in veterans beyond PTSD and mild TBI. Results highlight that blast exposure severity may be a more relevant risk factor than deployment mild TBI in combat veterans and should be considered in the etiology of psychiatric symptom presentation and complaints. Further, severity of psychological distress due to the combat environment may be an explanatory mechanism by which blast exposure mediates the relationship between mild TBI and symptom outcomes.

1. Introduction

Exposure to blast and explosive events is common for military service members during training and deployment. However, relatively little is known about how exposure to these events affects symptom presentation, particularly outside the context of mild traumatic brain injury (TBI) (Belding et al., 2021a). This is in part due to lack of an agreed-upon definition of what constitutes the state of having been *blast exposed*. Though physical injury characteristics of blast exposure are well-defined (i.e., primary, secondary, tertiary, quaternary), many blasts that service members experience do not result in injuries that fall within these categories. In addition, exposure to a blast or explosive event does not always result in symptoms congruent with a mild TBI (Carr et al., 2016; Rowland et al., 2020b; Taber et al., 2015). Recent work has just begun to propose empirical definitions of blast exposure and comprehensively evaluate experience of blast events outside of mild TBI (Belding et al., 2021a; Rowland et al., 2020b). Because of this, it is unclear what effects exposure to a blast may have on behavioral health outcomes independent from mild TBI, and what characteristics of blast exposure are associated with psychiatric (e.g., PTSD, depression, neurobehavioral) and health (e.g., sleep, pain) symptoms as well as overall quality of life.

The majority of our foundational knowledge of behavioral health effects of blast exposure is within the context of blast as a TBI mechanism (Belding et al., 2021b; Greer et al, 2016, 2018; Mac Donald et al., 2017). Specifically, a significant portion of human research on blast exposure evaluates consequences of primary blast mild TBI (i.e., mild TBI resulting from blast exposure without contribution of non-blast forces), compared to non-blast mild TBI (i.e., blunt mild TBI) (Belding

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et al., 2021b; Greer et al, 2016, 2018; Mac Donald et al., 2017). A recent systematic review of this literature indicated no significant differences in behavioral health outcomes between veterans with blast mild TBI and non-blast mild TBI(Greer et al., 2018). This outcome is not surprising because this review contrasts different mechanisms of mild TBI and does not consider blast characteristics (e.g., magnitude) or exposures to blast that do not result in a mild TBI. Within and outside of this review, some individual studies suggest subtle differences in functional outcomes in veterans with a history of blast mild TBI including greater service-connected disability ratings (Clark et al., 2009; Dismuke-Greer et al., 2018). as well as more severe psychiatric and health symptoms (Belanger et al., 2011; Belding et al., 2021b; Clark et al., 2009; Kennedy et al., 2010; Kontos et al., 2015). Notably, these differences are typically behavioral (e.g., PTSD symptoms) (Belanger et al., 2011; Clark et al., 2009; Kontos et al., 2013; Maguen et al., 2012; Sayer et al., 2008) neurobehavioral symptoms including sleep (Belanger et al., 2011; Belding et al., 2021b; Reid et al., 2014) or cognitive with strong relationships to affective outcomes (e.g., learning/memory, reaction time) (Kontos et al, 2013, 2015). The presence of mixed evidence suggests that primary blast exposure may contribute to psychiatric and health symptoms in a manner that has not been previously detected when focusing solely on exposures resulting in a TBI. Rather, effects that are suggested by these subtle differences may be better detected and explained by evaluating primary blast exposure independent of mild TBI.

In support of this, there is a growing literature investigating the effects of primary blast exposure independent of TBI (i.e., primary blast exposure that does not result in symptoms consistent with TBI) (Belding et al., 2021a; Martindale et al., 2020b; Walker et al., 2015). These studies generally demonstrate that effects of blast on biological and behavioral outcomes can occur independent from mild TBI characteristics (e.g., history, frequency, severity) as well as other factors, such as common mental health comorbidities (e.g., posttraumatic stress disorder) and combat exposure. Specifically, exposure to primary blast has been shown to affect brain structure and function in humans (Carr et al., 2016; Stone et al., 2020), altering both white matter integrity (Taber et al., 2015; Trotter et al., 2015a) and functional brain networks (Robinson et al, 2015, 2017). However, there are relatively few studies evaluating behavioral outcomes associated with primary blast exposure in humans. Studies of service members undergoing breacher training (the process by which doors are opened by force, frequently involving explosions) have demonstrated increases in the number and severity of reported symptoms as a result of repeated exposure to controlled blasts (Carr et al, 2015, 2016). Sleep quality (Stocker et al., 2016) and pain (Stratton et al., 2014) have shown to be affected by history of primary blast exposure. Though beyond the scope of this manuscript, effects of primary blast exposure on cognitive function (specifically reaction time) beyond mild TBI, have also been demonstrated in both acute (Haran et al., 2019) and chronic (Martindale et al., 2020b) samples.

As demonstrated, research focusing specifically on blast typically diverges into studies of primary blast exposure and studies of effects of blast forces present during the occurrence of a mild TBI (i.e., blast-plus, primary blast mild TBI). Few studies gather data encompassing both experiences, though significant variability is present within this literature due to differences in sample composition as well as measurement and definition of blast exposure. The present analysis evaluates how blast exposure severity (defined as maximum pressure experienced as a result of a blast (Rowland et al., 2020b), described subsequently in methods) affects behavioral health outcomes beyond the effects of PTSD and deployment mild TBI in a sample that spans the full range of exposures to blast (i.e., small controlled primary blast up to concussive blast-plus exposures). We expected that greater reported blast severity would be associated with more severe psychiatric and neurobehavioral symptoms, as well as poorer sleep quality, higher pain interference, and poorer quality of life. Because blast severity has been shown to exacerbate effects of mild TBI on cognitive outcomes (Martindale et al., 2020b), we also evaluated moderating effects among PTSD diagnosis, deployment mild TBI history, and blast severity on outcomes of interest. We expected that the interaction between blast severity and deployment mild TBI history would be associated with the highest symptom reports.

2. Materials and method

2.1. Participants

Data were collected as part of Study 34 funded by the Chronic Effects of Neurotrauma Consortium (CENC). The purpose of this study was to evaluate the effects of primary blast exposure on the brain and behavior. Participants were recruited through brochures and flyers posted throughout the local VA Healthcare System campuses, direct mailings, and advertisements at regional veteran centers and community events. Participants were initially screened by telephone for eligibility. All participants provided informed consent prior to participation. All study procedures were approved by the local Institutional Review Board. All study procedures were conducted for research purposes only.

Eligibility criteria were: one or more combat deployment after 9/11/2001, English fluency, 18 years of age or older, able to comply with instructions to complete study tasks, and able to provide informed consent. Exclusion criteria were a history of moderate or severe TBI (loss of consciousness >30 min; posttraumatic amnesia lasting >24 h; alteration of consciousness >24 h), any penetrating head injury, presence of neurologic disorder, severe mental illness, dementia, current substance use disorder, or psychotic symptoms.

Final eligibility was evaluated at the study visit, which included the Structured Clinical Interview for *DSM-IV* Disorders (SCID; First et al., 1996) to determine severe mental illness diagnoses. Participants were excluded from analyses if they failed the Structured Inventory of Malingered Symptoms (SIMS; Smith and Burger, 1997). Of the 341 enrolled participants, 47 (13.82%) failed the SIMS, 26 (7.65%) had a history of greater than mild TBI, and one additional participant was excluded for missing data. Reported exclusion percentages are not mutually exclusive by category. The final sample size for analyses was $N = 275$.

2.2. Measures

Interviews. Lifetime blast events were evaluated using the Salisbury Blast Interview (SBI; Rowland et al., 2020b). Maximum pressure ratings were used to represent blast severity in analyses. On the SBI, pressure ratings are provided on a behaviorally-anchored scale of 0 (no pressure/no blast exposure) to 5 (resulted in greater than minor injury) and have been shown to be a good indicator of severity, based on analyses predicting an outcome of TBI. The Mid-Atlantic MIRECC Assessment of TBI (MMA-TBI; Rowland et al., 2020a) evaluated lifetime TBI history and severity. Deployment mild TBI was chosen as the independent variable due to previous literature that indicates deployment mild TBI is more likely to affect psychological outcomes in Veterans than mild TBI acquired outside of a deployment environment (Martindale et al., 2018). The Clinician Administered PTSD Scale for DSM-5 (CAPS-5; Weathers et al., 2013) determined current and lifetime PTSD diagnosis.

Psychiatric Symptoms. The PTSD Checklist for DSM-5 (PCL-5; Blevins et al., 2015) is a 20-item questionnaire that evaluates the extent to which a respondent has been bothered by posttraumatic stress symptoms over the past 30-day period. Total scores range from 0 to 80, with higher scores reflecting greater problems. The 9-item Patient Health Questionnaire (PHQ-9; Kroenke et al., 2001) evaluates depressive symptoms over the previous 14 days. Total scores range from 0 to 27, with higher scores representing more severe symptoms.

Health and Well-Being. The Neurobehavioral Symptom Inventory (NSI; King et al., 2012) is a 22-item scale that evaluates post-concussion symptoms over the past month. Total scores range from 0 to 88, with higher scores reflecting greater reported problems. The Pittsburgh Sleep

Quality Index (PSQI; Buysse et al., 1989) is a 19-item questionnaire that evaluates sleep quality over the past 30 days. Global scores range from 0 to 21, with higher scores reflecting poorer sleep quality. The Patient Reported Outcomes Measurement Information System Pain Interference (PROMIS-PI; Amtmann et al., 2010) is a 6-item measure that evaluates the consequences of pain on aspects of an individual's life over the past week. Higher scores reflect greater functional interference. PROMIS-PI scores were converted to T-scores ($M = 50$, $SD = 10$) for analysis.

The Quality of Life after Brain Injury scale (QOLIBRI; von Steinbüchel et al., 2010) evaluates quality of life in the past week across domains of cognition, self, daily life and autonomy, social relationships, emotions, and physical problems. Because not all participants in this sample experienced a mild TBI, and those with mild TBI were in chronic stages, two minor alterations were made to this scale. First, reference to *since your brain injury* was removed from instructions. Second, two items that specifically reference a TBI event were removed. Participants responded to 35 total items. Because the QOLIBRI uses linear transformations that do not affect variability, raw scores with appropriate reverse scoring were used in analyses. Higher scores reflect better quality of life.

2.3. Data analysis

Analyses were conducted with SAS Enterprise Guide 7.1 (SAS Institute, Inc., Cary, NC). Bivariate Pearson correlations evaluated zero-order relationships between blast pressure and outcomes of interest. Combat exposure was the only demographic variable significantly associated with outcomes as well as age ($r = -0.13$, $p = .036$) and sex ($r = -0.24$, $p < .001$), and was therefore included as a covariate across all analyses. Hierarchical linear regressions evaluated the influence of maximum blast pressure (continuous; 0 = none experienced, 5 = severe) on outcomes beyond a current PTSD diagnosis (dichotomous) and deployment mild TBI status (dichotomous). Blast exposure severity was defined as maximum blast pressure experienced. No blast exposure was coded as 0 for blast pressure ratings. Confidence intervals are 95% and bootstrapped with 10,000 samples. Indirect (i.e., mediation) and interaction (i.e., moderation) effects were evaluated using the PROCESS 3.1 macro (Hayes, 2018). Both mediation and moderation adjusted for all independent variables. False discovery rate at $\alpha = 0.05$ corrected for multiple comparisons (Benjamini and Hochberg, 1995). The highest variance inflation factor was 1.71, indicating very low multicollinearity.

3. Results

Participant characteristics are reported in Table 1. Participants were 275 veterans (86.55% male) who experienced combat during a deployment in support of the wars in Iraq and Afghanistan. Most were White (58.12%) or Black (38.27%) and educated beyond a high school diploma, $M_{years} = 15.09$, $SD = 2.19$. Army veterans (71.84%) were highly represented in this sample, the average number of deployments was $M = 2.73$, $SD = 3.55$, mode = 1, and the most recent combat deployment occurred an average of $M = 9.82$, $SD = 3.54$, years prior to participation.

Most participants (71.27%) had blast exposure history, defined as experiencing any noticeable pressure wave resulting from an explosion (pressure rating ≥ 1). In addition, 29.82% had a current diagnosis of PTSD, and 45.45% experienced a mild TBI during deployment. Of those with mild TBI history, 76% ($n = 95$) had at least one TBI involving blast. Table 2 reports sample-level descriptive statistics of outcome measures. All were within expected ranges for the sample, though posttraumatic stress symptoms and sleep quality scores were slightly elevated, suggesting poorer outcomes. Table 3 illustrates correlations between independent and dependent variables.

Hierarchical regression results are reported in Table 4. Combat exposure was included as a covariate for all models. Current diagnosis of PTSD explained significant variance across all six outcomes (Model 1), which remained robust when adjusting for effects of deployment mild TBI and maximum blast pressure in subsequent models. Deployment mild TBI history explained significant additional variance beyond PTSD diagnosis across tested outcomes (Model 2); however, these effects were no longer significant when adjusting for maximum blast pressure in all analyses except for neurobehavioral symptoms. Maximum blast pressure accounted for significant additional variance in the omnibus model beyond combat exposure, PTSD diagnosis, and deployment mild TBI (Model 3) for PTSD symptoms, $\Delta R^2 = 0.017$, depressive symptoms, $\Delta R^2 = 0.020$, neurobehavioral symptoms, $\Delta R^2 = 0.018$, and sleep quality, $\Delta R^2 = 0.010$, but only had significant independent effects on posttraumatic stress, $B = 2.00$, $p = .009$, depressive, $B = 0.76$, $p = .011$, and neurobehavioral, $B = 1.69$, $p = .013$, symptoms.

Table 1
Sample demographics (N = 275).

Demographic	*M* (*SD*), range or *n* (%)
Age	41.55 (10.08), 23-71
Education (years)	15.09 (2.19)
Number of Deployments	2.73 (3.55), 1-50
Years since most recent Combat Deployment	9.82 (3.54), 1.25–16.70
Sex	
Male	238 (86.55%)
Female	37 (13.45%)
Race*	
White/Caucasian	161 (58.12%)
Black/African American	106 (38.27%)
Other	16 (5.78%)
Branch of Service	
Air Force	28 (10.11%)
Army	199 (71.84%)
Marine Corps	27 (9.75%)
Navy	21 (7.58%)
Current PTSD Diagnosis	82 (29.82%)
Deployment mild TBI	125 (45.45%)
Years since Deployment TBI (*n* = 125)	10.62 (4.07), 0.91–27.32
Blast Exposed†	196 (71.27%)
Maximum Blast Pressure Rating	1.83 (1.54), 0-5
Yards from Blast (*n* = 196)	44.57 (150.21), 0-1760
Number of blast events (*n* = 196)	232.14 (669.32), 1-7202
Years since most recent exposure (*n* = 196)	10.18 (4.68), 1.09–50.06

Note. * = indicates categories are not mutually exclusive. †Blast Exposed is defined as reporting a pressure rating of 1 or greater. Number of deployments includes contract deployments to warzones in support of the wars in Iraq and Afghanistan. Race was collapsed due to small numbers in categories; "Other" includes Native America/Alaska Native, Asian, Other, and Refused. Branch of Service indicates most recent branch of service. Branches of service have been collapsed to include Reserve and Guard units. PTSD = posttraumatic stress disorder. TBI = traumatic brain injury. Maximum Blast Pressure Rating is measured with the Salisbury Blast Interview (0–5) and includes the full sample; participants who were not exposed to blast have a pressure rating of 0.

Table 2
Sample outcome characteristics (N = 275).

	M	*SD*	Min.	Max.
DRRI-2-D Combat Exposure Total Score	34.00	14.47	16	93
PCL-5 Total Score	28.88	18.26	0	70
PHQ-9 Total Score	10.65	6.57	0	27
NSI Total Score	22.56	15.21	0	69
PSQI Global Score	10.38	4.22	1	21
PROMIS-PI T Score	54.80	9.54	40.7	77
QOLIBRI Total Score	80.49	27.47	9	134

Note. M = Mean, *SD* = standard deviation, Min and Max refer to sample minimum and maximum scores. PCL-5 = PTSD Checklist for DSM-5; PHQ-9 = Patient Health Questionnaire Major Depressive Disorder module; NSI = Neurobehavioral Symptom Inventory; PSQI = Pittsburgh Sleep Quality Index; PROMIS-PI = Patient Reported Outcomes Measurement Information System – Pain Interference; QOLIBRI = Quality of Life After Brain Injury scale.

Table 3
Bivariate correlations among independent and dependent variables (N = 275).

	Current PTSD Diagnosis		Deployment TBI		Maximum Blast Pressure	
	r	p	r	p	r	p
Deployment TBI	.11	.075	–	–	.49	<.001
Maximum Blast Pressure Rating	.22	.003	.49	<.001	–	–
PCL-5 Total Score	.51	<.001	.24	<.001	.33	<.001
PHQ-9 Total Score	.42	<.001	.17	.005	.24	<.001
NSI Total Score	.39	<.001	.25	<.001	.32	<.001
PSQI Global Score	.34	<.001	.17	.005	.24	<.001
PROMIS-PI T-Score	.29	<.001	.16	.010	.13	.035
QOLIBRI Total Score	-.36	<.001	-.18	.004	-.21	<.001

Note. Current PTSD diagnosis (0 = absent, 1 = present) was evaluated using the Clinician Administered PTSD Scale for DSM-5 (CAPS-5). Deployment mild TBI (0 = absent, 1 = present) was evaluated with the Mid-Atlantic MIRECC Assessment of Traumatic Brain Injury (MMA-TBI). Maximum Blast Pressure Rating refers to the highest reported lifetime pressure experienced as a result of a blast event (0 = none; 5 = severe) and was evaluated using the Salisbury Blast Interview (SBI).

3.1. Mediation and moderation

As demonstrated in the previous regression models, deployment mild TBI was significantly related to PTSD symptoms, depressive symptoms, and neurobehavioral symptoms beyond the effects of combat exposure and PTSD diagnosis (Model 2) but was no longer significant after the addition of maximum blast pressure. Mediation models examined whether blast severity accounted for the relationship between deployment mild TBI history and outcomes. All models covaried for current PTSD diagnosis and combat exposure. The indirect effect (i.e., mediation) of maximum blast pressure on the relationship between deployment mild TBI severity and outcomes was significant for posttraumatic stress, $B = 1.62$, CI[0.29, 3.32], depressive, $B = 0.61$, CI[0.11, 1.24], and neurobehavioral, $B = 1.38$, CI[0.16, 2.93], symptoms. As expected, maximum blast pressure did not mediate the relationship between PTSD diagnosis and any outcome after covarying for deployment TBI history and combat exposure.

There were no significant interaction effects (i.e., moderation) among any combination of independent variables.

Table 4
Hierarchical regression outcomes (N = 275).

Model		Omnibus Model			Parameter Estimates					
		R2	*p*	ΔR2 sig	*B*	*SEB*	*t*	*p*	LLCI	ULCI
Posttraumatic Stress Symptoms (PCL-5)										
Model 1*	PTSD Diagnosis†	0.289	<.001	—	18.86	2.08	9.06	<.001	14.76	22.96
Model 2*	PTSD Diagnosis†	0.302	<.001	0.006	18.88	2.07	9.13	<.001	14.81	22.94
	Deployment TBI†				4.94	2.20	2.24	0.026	0.61	9.27
Model 3*	PTSD Diagnosis†	0.319	<.001	<.001	18.17	2.06	8.81	<.001	14.11	22.23
	Deployment TBI				3.32	2.26	1.47	0.144	-1.14	7.77
	Maximum Blast Pressure†				2.00	0.76	2.64	0.009	0.51	3.49
Depressive Symptoms (PHQ-9)										
Model 1*	PTSD Diagnosis†	0.174	<.001	—	5.88	0.81	7.29	<.001	4.30	7.47
Model 2*	PTSD Diagnosis†	0.191	<.001	0.004	5.89	0.80	7.36	<.001	4.32	7.47
	Deployment TBI†				2.06	0.85	2.42	0.016	0.39	3.74
Model 3*	PTSD Diagnosis†	0.211	<.001	<.001	5.62	0.80	7.04	<.001	4.05	7.20
	Deployment TBI				1.45	0.88	1.66	0.099	-0.27	3.18
	Maximum Blast Pressure†				0.76	0.29	2.58	0.011	0.18	1.33
Neurobehavioral Symptoms (NSI)										
Model 1*	PTSD Diagnosis†	0.185	<.001	—	11.69	1.86	6.30	<.001	8.04	15.34
Model 2*	PTSD Diagnosis†	0.204	<.001	0.002	11.70	1.84	6.37	<.001	8.09	15.32
	Deployment TBI†				4.92	1.96	2.51	0.013	1.07	8.78
Model 3*	PTSD Diagnosis†	0.222	<.001	<.001	11.10	1.84	6.05	<.001	7.49	14.72
	Deployment TBI				3.55	2.01	1.76	0.079	-0.42	7.52
	Maximum Blast Pressure†				1.69	0.67	2.51	0.013	0.37	3.02
Sleep Quality (PSQI)										
Model 1*	PTSD Diagnosis†	0.133	<.001	—	2.88	0.53	5.42	<.001	1.83	3.92
Model 2*	PTSD Diagnosis†	0.139	<.001	0.149	2.88	0.53	5.43	<.001	1.84	3.92
	Deployment TBI				0.77	0.56	1.36	0.175	-0.34	1.88
Model 3*	PTSD Diagnosis†	0.149	<.001	0.010	2.76	0.53	5.18	<.001	1.71	3.80
	Deployment TBI				0.48	0.58	0.83	0.408	-0.67	1.63
	Maximum Blast Pressure				0.35	0.20	1.78	0.076	-0.04	0.73
Pain Interference (PROMIS-PI)										
Model 1*	PTSD Diagnosis†	0.087	<.001	—	5.68	1.23	4.61	<.001	3.26	8.11
Model 2*	PTSD Diagnosis†	0.098	<.001	0.011	5.69	1.23	4.64	<.001	3.28	8.11
	Deployment TBI				2.37	1.31	1.81	0.071	-0.21	4.94
Model 3	PTSD Diagnosis†	0.098	<.001	0.865	5.67	1.24	4.58	<.001	3.23	8.11
	Deployment TBI				2.32	1.36	1.70	0.089	-0.36	5.00
	Maximum Blast Pressure				0.06	0.46	0.13	0.899	-0.84	0.95
Quality of Life (QOLIBRI)										
Model 1*	PTSD Diagnosis†	0.133	<.001	—	-20.50	3.46	-5.92	<.001	-27.32	-13.68
Model 2*	PTSD Diagnosis†	0.147	<.001	0.012	-20.52	3.44	-5.96	<.001	-27.30	-13.74
	Deployment TBI†				-7.51	3.67	-2.05	0.042	-14.73	-0.29
Model 3	PTSD Diagnosis†	0.154	<.001	0.080	-19.85	3.46	-5.73	<.001	-26.67	-13.03
	Deployment TBI				-5.96	3.80	-1.57	0.118	-13.45	1.52
	Maximum Blast Pressure				-1.91	1.27	-1.50	0.136	-4.41	0.60

Note. ΔR^2 sig = *p*-value for change in R^2; B = standardized beta; LLCI = lower limit 95% confidence interval; ULCI = upper limit 95% confidence interval. PTSD diagnosis (0 = absent, 1 = present) was evaluated using the CAPS-5. Deployment TBI (0 = absent, 1 = present) was evaluated with the MMA-TBI. Maximum Blast Pressure (0 = none, 5 = severe) was evaluated using the SBI. *indicates significant outcome after false discovery rate (α = 0.05) correction for multiple comparisons at the omnibus level. †indicates significant effect within the model. All models covary for combat exposure as measured by the DRRI-2-D (combat exposure) total score (not reported).

3.2. Post-Hoc considerations

We investigated alternative explanatory variables related to blast by including competing blast characteristics in a single linear regression model predicting outcomes. As illustrated in Table 5, years since exposure, frequency of exposure, and distance from an explosion were not significantly associated with outcomes beyond blast pressure. Additionally, adjusting for history of non-deployment mild TBI or number of deployment mild TBIs did not alter outcomes. Finally, we evaluated how results changed if PTSD symptom severity from the CAPS-5 replaced PTSD diagnosis. This exploratory analysis was not included in planned analyses because this effectively compares symptoms as measured by one tool to highly similar symptoms measured by another (e.g., posttraumatic stress symptoms measured by both the CAPS-5 and PCL-5). As expected, blast variables were no longer significant in the final models for each outcome, and CAPS-5 PTSD symptom severity was the sole significant predictor variable. Though the variables in this exploratory analysis were collinear, these findings inform that blast severity may not be independent from symptom distress, or could alternatively be creating these symptoms, as discussed below. However, importantly, blast severity does not act as a proxy for symptom distress, as evidenced by the lack of an interaction effect between PTSD diagnosis and blast severity across outcomes.

Table 5
Models with competing blast characteristics (N = 275).

	Parameter Estimates					
Model	*B*	*SEB*	*t*	*p*	LLCI	ULCI
PTSD Symptoms (PCL-5)						
Maximum Blast Pressure*	2.28	0.78	2.94	.004	0.75	3.81
Years Since Exposure	0.24	0.20	1.19	.236	−0.16	0.64
Number of Exposures	0.00	0.00	−0.08	.938	0.00	0.00
Minimum Distance	0.00	0.00	−0.38	.703	0.00	0.00
Depressive Symptoms (PHQ-9)						
Maximum Blast Pressure*	0.82	0.30	2.72	.007	0.23	1.42
Years Since Exposure	−0.01	0.08	−0.09	.925	−0.16	0.15
Number of Exposures	0.00	0.00	−0.22	.830	0.00	0.00
Minimum Distance	0.00	0.00	0.52	.601	0.00	0.00
Neurobehavioral Symptoms (NSI)						
Maximum Blast Pressure*	1.85	0.68	2.71	.007	0.50	3.20
Years Since Exposure	−0.05	0.18	−0.27	.787	−0.40	0.30
Number of Exposures	0.00	0.00	0.43	.669	0.00	0.00
Minimum Distance	0.00	0.00	−0.55	.583	0.00	0.00
Sleep Quality (PSQI)						
Maximum Blast Pressure*	0.38	0.20	1.88	.062	−0.02	0.78
Years Since Exposure	0.00	0.05	−0.03	.977	−0.10	0.10
Number of Exposures	0.00	0.00	−0.11	.915	0.00	0.00
Minimum Distance	0.00	0.00	−0.09	.928	0.00	0.00
Pain Interference (PROMIS-PI)						
Maximum Blast Pressure	0.15	0.47	0.32	.752	−0.78	1.08
Years Since Exposure	0.19	0.12	1.55	.123	−0.05	0.43
Number of Exposures	0.00	0.00	−0.13	.893	0.00	0.00
Minimum Distance	0.00	0.00	0.06	.951	0.00	0.00
Quality of Life (QOLIBRI)						
Maximum Blast Pressure	−2.10	1.32	−1.59	.114	−4.70	0.51
Years Since Exposure	0.21	0.34	0.60	.548	−0.47	0.88
Number of Exposures	0.00	0.00	0.10	.917	−0.01	0.01
Minimum Distance	0.00	0.00	−0.70	.485	−0.01	0.00

Note. All models covary for combat exposure (DRRI-2-D), mild deployment TBI, and current PTSD diagnosis (not reported). For individuals who were not blast exposed, years since deployment was used as a proxy. The difference in years since deployment and time since blast exposure was not significantly different, $M_{diff} = -0.45$, $t(251) = -1.90$, $p = .059$; therefore, years since deployment was considered an acceptable proxy for those with no history of blast exposure. PCL-5 = PTSD Checklist for DSM-5; PHQ-9 = Patient Health Questionnaire Major Depressive Disorder module; NSI = Neurobehavioral Symptom Inventory; PSQI = Pittsburgh Sleep Quality Index; PROMIS-PI = Patient Reported Outcomes Measurement Information System – Pain Interference; QOLIBRI = Quality of Life After Brain Injury scale. *indicates significant effects after adjusting for multiple comparisons.

4. Discussion

The results of this study demonstrate that chronic mental health symptoms (posttraumatic stress, depression, and neurobehavioral) increase proportionately with blast exposure severity. These associations are independent from PTSD diagnosis and deployment mild TBI history. However, these findings did not extend to sleep quality, pain interference, or quality of life. Further, results demonstrate that blast exposure severity explains significant aspects of the relationship between deployment mild TBI history with posttraumatic stress, depressive, and neurobehavioral symptoms in this cohort of Iraq and Afghanistan combat veterans. Though prior studies have reported similar findings acutely following blast exposure (Carr et al, 2015, 2016), this is the first demonstration of increased severity of psychiatric symptoms in the chronic phase (i.e., greater than one year) following blast exposure.

Though a significant amount of research on symptom outcomes in veterans of the wars in Iraq and Afghanistan focuses on PTSD and mild TBI, many injuries sustained during the recent conflicts involve exposure to blast (Terrio et al., 2009). Studies evaluating blast mild TBI generally indicate little to no difference in symptom report when compared to non-blast TBI mechanisms (Greer et al., 2018). In contrast, literature examining repetitive, controlled low-level blast exposure not resulting in TBI has demonstrated significant increases in psychiatric symptoms acutely following exposure (Carr et al, 2015, 2016). The current study extends these findings by examining the full spectrum of blast exposure (e.g., small controlled blasts without resulting TBI up to blast-plus mild TBI) in the chronic phase, demonstrating a significant contribution of blast exposure severity to increased severity of psychiatric symptoms that is independent of both PTSD and deployment mild TBI history.

The relationship between blast exposure severity and mild TBI is complex. It is clearly possible for primary blast exposure (i.e., without additional forces) to injure the brain, and the greater severity of a blast, the more likely a resulting TBI becomes (Robinson et al., 2015; Rowland et al., 2020b; Taber et al., 2015; Trotter et al., 2015b). Our results suggest that blast exposure severity may be more important to consider than symptoms congruent with mild TBI in the etiology of symptom presentation in Iraq and Afghanistan combat veterans. Without adjusting for blast severity, deployment mild TBI was a significant contributor to symptom presentation across all outcomes. When blast severity was included in the model, deployment mild TBI history was no longer a significant predictor of any outcome. This indirect (i.e., mediational) relationship was confirmed by further analyses demonstrating that the influence of deployment mild TBI history on PTSD, depressive, and neurobehavioral symptoms was explained by severity of blast exposure. These findings suggest that an understanding of history of blast exposure may be more informative regarding behavioral health outcomes than an understanding of mild TBI history in combat veterans. Nevertheless, the current study did not include participants with moderate or severe TBI, which could potentially alter these relationships.

Blast severity was additionally observed to have an effect both beyond and independent of PTSD diagnosis, suggesting that these factors each contribute uniquely to symptom report. It is well established that a diagnosis of PTSD is associated with increased levels of symptom report across a broad range of outcomes, which is mirrored in the present results (Gros et al, 2010, 2012; Martindale et al., 2020a). The independent contribution of blast severity to symptom report in the chronic stage is a novel finding. Further work will be required to identify specific mechanisms of this relationship. Though blast severity was associated with increasing symptom report beyond PTSD diagnosis, this relationship was no longer present when current PTSD symptoms replaced PTSD diagnosis in our exploratory analytic models. This was not unexpected given the strong influence of blast severity on PTSD symptoms and the significant overlap of PTSD symptoms with many of the other symptom outcomes analyzed. This exploratory analysis simply highlights the robust relationship between blast severity and PTSD symptoms and suggests that the effect of blast severity on PTSD symptom presentation may represent an interaction outside of PTSD diagnosis, confirming that blast severity contributes to psychiatric symptom severity.

The current results highlight that blast exposure severity may be a more relevant risk factor for poorer long-term outcomes than deployment TBI in combat veterans. Though our results suggest an indirect effect of blast exposure, such that blast influences outcomes but does not have an independent effect, there are other possibilities. Specifically, evidence from neuroimaging supports that blast exposure can affect brain structure and function in the absence of symptoms consistent with mild TBI (Stone et al., 2020; Taber et al., 2015). Therefore, blast exposure may have an independent effect on symptom outcomes that are not possible to detect with this data. However, it is also possible that history of blast exposure may act as a proxy for another important factor, such as overall combat exposure or psychiatric symptom severity that may lead to poorer outcomes. For example, there may be something about the environment (e.g., higher operational tempo) in which a blast occurs that may contribute to enduring symptoms beyond blast or TBI. In addition to considering blast exposure characteristics independently, future research should evaluate additional factors present that may better explain outcomes. This will provide a better understanding about how experiencing a blast may or may not affect service members long-term.

This study is not without limitations. First, this is a combat veteran sample and may not generalize to non-combat veterans or to civilians. The proportion of women represented in this sample is congruent with the US military population but precluded us from being able to make meaningful sex comparisons. Additionally, this is a cross-sectional study, and therefore we cannot make causal statements or speculate on potential effects of pre-existing conditions based on the available data. TBI, blast, and PTSD were assessed using semi-structured interviews instead of primary source materials creating the potential for recall bias. Strengths of the present study include evaluation of symptom validity using a standalone measure and use of gold-standard clinical interviews.

5. Conclusions

Results of the present study indicated that higher blast severity was associated with higher chronic mental health symptoms (posttraumatic stress, depression, and neurobehavioral), beyond PTSD diagnosis and deployment mild TBI history. Additionally, blast severity accounted for significant aspects of the relationship between deployment mild TBI history and these behavioral health outcomes. Findings suggest that blast severity may be a more relevant risk factor than deployment mild TBI in the symptom presentation among Iraq and Afghanistan combat veterans.

Disclosure

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Disclaimer

The views, opinions and/or findings contained in this article are those of the authors and should not be construed as an official US Department of Veterans Affairs or US Department of Defense position, policy or decision, unless so designated by other official documentation.

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Sarah L. Martindale: Conceptualization, Methodology, Formal analysis, Investigation, Supervision, Writing – original draft, Writing – review & editing, Project administration. **Anna S. Ord:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Lakeysha G. Rule:** Investigation, Writing – original draft, Writing – review & editing. **Jared A. Rowland:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Supervision, Writing – original draft, Writing – review & editing, Project administration.

Declaration of competing interest

The authors have no conflicts of interest to disclose.

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