Research Article

Close proximity to blast: No long-term or lasting effect on cognitive performance in service members with and without TBI during blast exposure

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Abstract

Objective: Blast related characteristics may contribute to the diversity of findings on whether mild traumatic brain injury sustained during war zone deployment has lasting cognitive effects. This study aims to evaluate whether a history of blast exposure at close proximity, defined as exposure within 30 feet, has long-term or lasting influences on cognitive outcomes among current and former military personnel. **Method:** One hundred participants were assigned to one of three groups based on a self-report history of blast exposure during combat deployments: 47 close blast, 14 non-close blast, and 39 comparison participants without blast exposure. Working memory, processing speed, verbal learning/memory, and cognitive flexibility were evaluated using standard neuropsychological tests. In addition, assessment of combat exposure and current post-concussive, posttraumatic stress, and depressive symptoms, and headache was performed via self-report measures. Variables that differed between groups were controlled as covariates. **Results:** No group differences survived Bonferroni correction for family-wise error rate; the close blast group did not differ from non-close blast and comparison groups on measures of working memory, processing speed, verbal learning/memory, or cognitive flexibility. Controlling for covariates did not alter these results. **Conclusion:** No evidence emerged to suggest that a history of close blast exposure was associated with decreased cognitive performance when comparisons were made with the other groups. Limited characterization of blast contexts experienced, self-report of blast distance, and heterogeneity of injury severity within the groups are the main limitations of this study.

Keywords: brain injuries; traumatic; brain injury; chronic; post-traumatic headache; psychological distress; stress disorder; post-traumatic; military

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Introduction

The prevalence of improvised explosive devices (IEDs) during Operations Enduring Freedom, Iraqi Freedom, and New Dawn (OEF/OIF/OND) exposed US military service members to blast injury at a rate not experienced in previous conflicts (Owens et al., 2008). In theory, blast has the potential to result in brain injury when energy emanating from the explosion is transferred into compressed pressure waves that can pass through tissues within the cranium at a rapid speed (DePalma et al., 2005; Ling et al., 2009). Waves induce particle motion as they pass through tissues with varying densities, such as air-fluid or fluid-solid interfaces, making them particularly vulnerable to blast injury (DePalma et al., 2005; Taber et al., 2006). Blast waves can also reflect off objects, such as walls, to produce complex wave fields. It is unknown exactly how rapid pressure gradients injure brain tissue, but blast within the context of combat is almost always accompanied by secondary, tertiary, or quaternary effects (Bryden et al., 2019). Secondary and tertiary effects involve mechanisms similar to blunt trauma to the brain in that objects and debris thrown by explosions can hit and penetrate the head (secondary effect), or the service member can be thrown a distance by the energy from the explosion to hit hard surfaces (tertiary effect). Quaternary effects include burns, toxic fumes, or effects of other explosive products.

There is some evidence of subtle neural compromise following blast-related traumatic brain injury (TBI). For example, a history of mild TBI (mTBI) sustained within a blast context has been found to be associated with abnormal activation of neural systems involved in response selection and inhibition (Fischer et al., 2014; Scheibel et al., 2012) and with resting state connectivity (Gilmore

et al., 2016; Han et al., 2014; Huang et al., 2017; Robinson et al., 2015). Blast has also been associated with white matter microstructural abnormalities (Davenport et al., 2012; Mac Donald et al., 2017; Mac Donald et al., 2011; Taber et al., 2015; Yeh et al., 2014) and with cortical thinning (Clark et al., 2018; Eierud et al., 2019; Tate et al., 2014). Blast intensity specifically has been associated with the number of white matter hyperintensities (Martindale et al., 2018), though not all studies have found support for structural abnormalities (Davenport et al., 2015; Levin et al., 2010). Neuroimaging findings within the cortical region raise the possibility that blast may have physiological effects on the brain, due to varying tissue density, even when other more vulnerable bodily regions escape injury (e.g. lungs, ears).

Despite evidence supporting some physiological sequelae from mTBI within a context of blast, studies have not reliably demonstrated that these sequelae have long-term cognitive consequences. Processing speed and verbal memory deficits have been observed during the acute stage up to seven days after mTBI sustained within a blast context (Kontos et al., 2015; Luethcke et al., 2011), but most studies do not find cognitive deficits after three months of injury (Frencham et al., 2005; Iverson, 2005; Vasterling et al., 2012). A majority of the studies that compare mTBI within a blast context to a non-blast context do not find differences due to the mechanism of injury (Belanger et al., 2009; Cooper et al., 2012; Greer et al., 2017; Storzbach et al., 2015). Some exceptions have been reported though. For example, Lange and colleagues found that mTBI within a blast context was associated with better cognitive performance compared to mTBI from mechanisms not associated with blast; however, effects were ameliorated after controlling for psychological factors (Lange et al., 2012). Martindale and colleagues reported that blast pressure severity exacerbated the effects of mTBI on attention (Martindale et al., 2020).

Several factors may contribute to the heterogeneity of findings following mTBI sustained during OEF/OIF/OND. First, while the majority of these injuries are associated with blast, some involve blunt-force trauma, and studies typically do not separate these mechanisms of injury. Second, service members deployed to OEF/OIF/OND may also engage in activities associated with low-level blast, such as explosive ordnance disposal or the firing of large weapons. Controlled blast may have different effects than blast experienced in an uncontrolled context due to precautions taken during controlled blasts, such as the use of cover to shield service members from the most deleterious effects. It is yet unknown which aspects of blast context are associated with physiological or cognitive sequelae. Early animal studies suggested peak pressure as important (Ling et al., 2009). Because peak pressure dissipates over distance, some assessment instruments, such as the Boston Assessment of Traumatic Brain Injury Lifetime interview, inquire about distance to blast as a proxy for severity of blast exposure (Fortier et al., 2014). Others suggest that blast pressure, as felt by service members, may be a better measure of severity of TBI sustained in a context of blast during deployment (Martindale et al., 2020). Yet others have proposed estimates of lifetime blast exposure based on a history of use of weapons that create blast pressure (Modica et al., 2021). Grande and colleagues reported that being within 10 meters of blast was associated with decreased verbal memory, regardless of the presence of mTBI (Grande et al., 2018). It is possible that some characterization of blast can be reliably associated with cognitive sequelae, but the medical community has not yet documented such a relationship.

Another factor that likely contributes to the heterogeneity of cognitive sequelae is the psychological trauma that frequently accompanies combat blast events, including the witnessing of severe injury or death (Hoge et al., 2008). There is evidence that blast-related mTBI is associated with greater posttraumatic stress symptoms than non-blast mTBI (Kennedy et al., 2010; Ryan-Gonzalez et al., 2019) and one meta-analysis found that executive dysfunction is related to posttraumatic stress symptoms (Woon et al., 2017). Other studies have shown that posttraumatic stress disorder (PTSD) explains cognitive deficits in veterans better than mTBI (Hantke et al., 2021; Vasterling et al., 2012). Thus, controlling or accounting for the effects of posttraumatic stress is important in understanding effects of blast exposure on cognitive functioning.

Whether there is a reliable and valid measure of blast overpressure with a long-lasting relationship with cognitive performance is still an open question. This study contributes to this effort by evaluating whether distance to blast has a long-term influence on cognitive outcome following OEF/OIF/OND deployment. Of various estimates of the severity of blast exposure, this study chose distance to blast because there has been at least two reports that blast in close range may have long-term sequelae (Grande et al., 2018; Robinson et al., 2015) and it is a measure available within our dataset. Because the goal is to evaluate effects of distance to blast, we did not limit our analyses to individuals who reported symptoms of mTBI. We seek to replicate Grande and colleagues' findings (Grande et al., 2018), and therefore hypothesized that those within close proximity of blast would demonstrate decreased verbal memory compared to those not within close proximity of blast. Because deployment to a combat zone can be associated with intense stress that can itself be associated with cognitive inefficiencies, we statistically control for the severity of post-traumatic stress symptoms that may mediate the cognitive effects of blast.

Method

This cross-sectional study included three groups of participants based on a self-reported proximity to the nearest primary blast: 1) *close blast group*: close proximity to blast with or without symptoms of mTBI; 2) *non-close blast group*: non-close proximity to blast with or without symptoms of mTBI; and 3) *comparison group*: no exposure to blast and no symptoms of mTBI.

Participants

Service members and veterans from 18 to 65 years of age with a history of deployment to OEF/OIF/OND were eligible to participate in this study. Participants were recruited from military and Veterans Administration (VA) hospitals in the southern part of the United States using flyers placed in various clinics, clinical referral, and by word-of-mouth. Exclusionary criteria were as follows: history of pre- or post-deployment concussion that required hospitalization; pre-existing neurological disorder associated with cerebral dysfunction and/or cognitive deficit; or pre-existing severe psychiatric disorder including alcohol or drug misuse. The study recruited three groups of participants, a mTBI group, a blast-exposed group without mTBI, and a comparison group. mTBI was defined using VA/Department of Defense (DoD) criteria of: Loss of consciousness less than or equal to 30 min, alteration of consciousness less than or equal to 24 h, or posttraumatic amnesia (PTA) less than or equal to 24 h; and no positive neuroimaging findings. For the mTBI group, the injury must have been sustained on deployment and occurred at least 3 months prior to evaluation. Additionally, they could not have had a history of moderate or severe TBI, and if the only criterion met for mTBI was alteration

Table 1. Correspondence between present group membership and membership targeted by recruitment

	Close blast	Non-close blast	Comparison
	(n = 47)	(n = 14)	(n = 39)
mTBI	39	9	0
Blast without mTBI	6	5	0
Comparison	2*	0	39

Note: *Participants were recruited and enrolled into the Comparison group but were later revealed to have had blast exposure.

of consciousness, the duration may not have been less than five minutes. For the blast-exposed group without mTBI, participants must have had a history of exposure to blast without symptoms that meet criteria for mTBI; nor could they have had a history of impairment of consciousness, PTA, or other evidence of intracranial injury. For the comparison group, if they had a non-cranial injury, they must have been more than 3 months post-injury at evaluation; they may not have had a history of impairment of consciousness, PTA, or other evidence of intracranial injury; and they may not have had a history of blast exposure. Our previous work showed no difference between mTBI and the control group (no history of mTBI or exposure to blast) on cognitive outcome (Troyanskaya et al., 2015).

For the purpose of this particular blast-related hypothesis, participants were re-grouped according to their proximity to blast. There are no empirical guidelines on what constitutes close proximity to blast. Grande and colleagues defined close proximity as within 10 meters of blast (Grande et al., 2018). They used the Boston Assessment of Traumatic Brain Injury interview (Fortier et al., 2014), which asked for self-reported distance to blast in the following categories: 0–10, 11–25, 26–100 meters. Our polytrauma interview used the following distance categories: less than 10 feet, 10–30, 30–50, more than 50 feet. To compare our findings to Grande and colleagues', we defined the close blast group as within 30 feet of a blast (approximately 9 meters) regardless of whether they met criteria for mTBI (n = 47; 39 (83%) met mTBI criteria). Participants who reported having experienced blast that occurred beyond 30 feet away were categorized into the non-close blast group (n = 14; 9 (64%) met mTBI criteria). Those who had never been exposed to blast and had no mTBI were categorized into the comparison group (n = 39). Those who had blunt mTBI with no blast exposure were not included (n = 7). Correspondence between recruited and present group membership is presented in Table 1.

Injury characteristics and deployment-related information

A semi-structured polytrauma interview was used to assess lifetime history of TBI (including presence and duration of loss of consciousness, alteration of consciousness, and PTA for most severe and most recent TBI) and any extra-cranial deployment-related injuries, number of combat deployments, number of blasts, proximity of the nearest blast, and type of explosive devices (Belanger et al., 2009; Troyanskaya et al., 2015). A masters-level study coordinator conducted this interview, and when multiple TBI or blast events were reported, the exposure during deployment that the participant considered most severe was queried as the index event. To corroborate participants' reports, the study coordinator reviewed available medical records; however, in many instances documentation of the reported injury/event could not be found due to many events occurring during combat and away from

medical care. Combat experience was measured using the *Combat Exposure Scale,* a 7-item self-report measure of wartime stressors rated on a 5-point Likert-like scale (Keane et al., 1989). Scores range from 0 to 41 with higher scores indicative of greater combat stress. Posttraumatic stress symptom severity was measured using the *PTSD Checklist, Civilian version (PCL-C),* a 17-item self-report measure of symptom severity within the last month that corresponds to the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition criteria for PTSD (Dobie et al., 2002; Weathers et al., 1993). Each item was rated from 1 to 5 (total score 17–85), with higher scores indicating greater severity of posttraumatic stress symptoms. Post-concussive symptoms from the past two weeks were measured using the *Neurobehavioral Symptom Inventory (NSI),* a 22-item self-report measure endorsed by the DoD and VA to track neurocognitive complaints after TBI (Cicerone & Kalma, 1995; King et al., 2012). Each item is rated from 0 to 4 (total score 0–88) with higher scores indicating greater symptom burden. Additionally, depressive symptom severity was measured using the *Center for Epidemiological Studies, Depression (CES-D),* a 20-item self-report of depressive symptoms in the past week rated on a 4-point Likert-like scale (Radloff, 1977), with the total score ranging 0–60 and higher scores indicating greater symptom severity. Headache impact in the past four weeks was measured using the *Headache Impact Test, 6 Items Version (HIT6)* (Ware et al., 2000). Scores range from 6 to 78, with higher scores indicating greater functional limitation from headache.

Performance and symptom validity

Screening for suboptimal effort was performed using the Word Memory Test (Green, 2005). The NSI Validity-10 was used to screen for symptom over-reporting (Bodapati et al., 2019; Vanderploeg et al., 2014). The recommended cut-off scores for both measures were applied (Bodapati et al., 2019; Green, 2005; Vanderploeg et al., 2014).

Cognitive measures

Test of Nonverbal Intelligence, 4th Edition (TONI-4) was used to estimate the level of intelligence pre-injury. On each trial, participants saw a grid with a missing part and chose the most logical missing part from four or six options. Raw scores were converted to standard scores that have a mean of 100 and standard deviation of 15 based on age norms.

Four cognitive domains were evaluated using standardized objective neuropsychological tests, all of which have acceptable to good psychometric properties (Mitrushina et al., 2005a, 2005b; Strauss et al., 2006a, 2006b, 2006c; Tombaugh, 2006):

Working memory
Auditory consonant trigrams (ACT). During each trial, the participant heard three letters and a number, counted backwards by counts of three from that number until told to stop, then recalled the three letters heard at the start of the trial. The duration of counting backwards was 9, 18, or 36 seconds, which made up the three delay conditions. The numbers of letters correctly recalled was tallied across five trials for 0–15 points per condition.

Paced Auditory Serial Addition Test (PASAT). This is a serial addition test where participants heard pre-recorded series of single digit numbers and summed up the two most recent digits prior to the presentation of the next digit. We administered two trials,

one at a rate of 3 s per digit and another at a rate of 2 s per digit (Diehr et al., 2003). There were 50 digits on each trial, yielding 0–49 points per trial.

Processing speed
Symbol Digit Modality Test (SDMT). This test employs a page with rows of symbols with a blank box underneath each symbol. The participant completed the page as quickly as possible by filling in the blank box with the correct number as identified by a row of keys at the top where each unique symbol was associated with a single digit number. The participant wrote on the page during the written condition and called out numbers for the research staff to record during the oral condition. The score was the number of correct responses in 90 s.

Trail Making Test (TMT), Part A. Participants drew a line to connect numbers one through 25 in sequential order. The numbers were randomly placed on an 8.5 × 11-inch piece of paper. If an error was made, staff gave feedback immediately by pointing to the last correct location and asked the participant to continue from that location. The score was the number of seconds required to complete this task.

Verbal learning and memory
Verbal Selective Reminding Test (VSRT). This list learning test consisted of 12 words presented at a rate of one word every two seconds. During the first trial, participants recalled as many words as possible. Staff then reminded the participant of other words on that list that were not recalled. Then the participant recalled the entire list again (second trial), and the same procedure repeated for a maximum of six trials or until the participant successfully recalled all 12 words on two consecutive trials, at which point any trials not administered were scored as correctly recalled. The Total Recall score was the number of correctly recalled words across six learning trials (0–72). The participant recalled the list again after a 30-minute delay for the Delay Recall score (0–12). Participants were not given notice that there would be a delayed recall.

Cognitive flexibility
Trail Making Test (TMT), Part B. Participants drew a line starting at the number one, connected to the letter A, and alternated between numbers and letters in sequential order through number 13 and letter L, which were all randomly placed on an 8.5 × 11-inch piece of paper. If an error was made, staff gave feedback immediately by pointing to the last correct location and asked the participant to continue from that location. The score was the number of seconds required to complete this task.

Procedures

Procedures were completed in compliance with standards for human research in accordance with the Helsinki Declaration. Participants were enrolled in the study using written informed consent procedures approved by the Institutional Review Board at each recruitment site. They then attended an individual screening visit in which they received a study-specific semi-structured polytrauma interview in which they provided a history of TBI, demographic information, and medical history. Participants also completed performance validity testing at this visit. Those who met all inclusionary and no exclusionary criteria were invited back to complete the remaining procedures. Veterans recruited at the

VA hospital were compensated for their time and effort. Service members recruited at the military hospital were not compensated in accordance with the Department of Defense policy against payment for off-duty participation from a Federal source (Kendall, 2011).

Statistical analyses

Background demographic, military, and injury variables were analyzed for differences between the two sites and the three participant groups. Analyses of variance (ANOVA) compared the continuous background variables between the three participant groups, independent samples *t*-tests compared the continuous background variables between the two sites and chi-square tests compared categorical background variables between groups and sites.

Raw scores from cognitive domains were used as dependent variables instead of standard scores. Standard scores are generally calculated in reference to some demographic characteristics; those who enter military service tend to be men and may not match the civilian sample from which standard scores are based (McGrath et al., 2020). Thus, raw scores were considered more appropriate dependent variables given that there was a control group against which to interpret findings. Bonferroni correction was applied within each cognitive domain to achieve a family-wise error rate set at *p*-value of 0.05. For example, a corrected *p*-value of 0.01 (p of 0.05/5 variables = 0.01) was used to determine significance for the five dependent variables in the working memory category. Background demographic, military, and behavioral health variables that differed between groups (p < 0.05) were entered as covariates when evaluating cognitive differences using analysis of covariance (ANCOVA).

Results

Of the 118 participants recruited, those who did not have documentation of having passed performance validity (n = 10), symptom validity (n = 1), and those who had blunt mTBI without blast exposure (n = 7) were excluded. The remaining 100 participants from the two sites differed in age, marital status and education. The military sample was older (*t*(98) = 2.15, *p* = .03), had proportionately more married participants ($\chi^2(3) = 22.55$, *p* < .01) and proportionately more with postgraduate education ($\chi^2(7) = 23.75$, *p* < .01) compared to the veteran sample. Demographic characteristics of the participants at each site are shown in the Supplemental Table.

Table 2 shows the three study groups' demographic and military characteristics. Groups differed on branch of service, gender distribution, education, and estimated preinjury intelligence. These variables were entered as covariates in subsequent analyses. The close blast and the non-close blast groups did not differ on injury characteristics (see Table 2). Notably, all three groups experienced their last deployment an average of seven years prior to evaluation, yielding cognitive functioning data associated with a remote history of deployment experience.

Table 3 shows group differences on self-reported symptom and behavioral health measures. Both close blast and non-close blast groups reported more post-concussive symptoms (NSI), traumatic stress symptoms (PCL-C), depressive symptoms (CES-D), and combat exposure relative to the comparison group. The close blast and non-close blast groups did not differ from each other on these measures (*p* > .05). A different pattern emerged for headaches, in

Table 2. Demographic and military characteristics according to group status

	Close blast	Non-close blast	Comparison		
	(n = 47)	(n = 14)	(n = 39)	F or χ^2 (df)	p-value
Demographic characteristics					
Age (years)	37 (8)	35 (8)	38 (9)	0.36 (2, 97)	0.70
Gender (M:F)	44:3	14:0	27:12	12.81 (2)	<.01
Education				32.57 (14)	<.01
High School	11	2	4		
Certificate	10	5	5		
Associate	14	4	11		
Bachelor	8	2	2		
Master	3	1	11		
Doctorate	0	0	6		
Other	1	0	0		
Intelligence (TONI-4 Index)	103 (8)	100 (8)	107 (8)	4.07 (2, 92)	**0.02**
Ethnicity				2.83 (2)	0.24
Hispanic/Latino	13	3	5		
Not Hispanic/Latino	34	11	34		
Race				4.09 (4)	0.39
Black/African-Am	5	4	5		
Other (non-white)	7	1	3		
Caucasian	35	9	31		
Marital Status				3.35 (6)	0.76
Single	9	2	6		
Married	25	9	27		
Divorced	12	3	6		
Separated	1	0	0		
Military characteristics					
Service Branches				18.42 (8)	**0.02**
Army	37	12	19		
Air Force	2	0	11		
Navy	3	0	4		
Marine Corps	5	2	4		
National Guard	0	0	1		
# of deployments	3 (2)	2 (2)	2 (1)	2.33 (2, 97)	0.10
Months since injury/deployment	80 (52)	79 (28)	82 (43)	0.04 (2, 97)	0.96
# of blasts	11 (21)	6 (8)	n/a	0.64 (1, 59)	0.43

Note: M = male; F = female; TONI-4 = Test of Nonverbal Intelligence, 4th Edition.

which the close blast group reported more significant impact of headaches than the comparison group only ($p < .01$). Table 4 shows that the NSI, PCL-C, and CES-D were highly correlated with each other and moderately but significantly correlated with combat exposure and the HIT-6. In analyses evaluating the influence of psychological distress, the PCL-C was chosen as the covariate to control for posttraumatic stress symptom severity; other measures of symptoms and experiences were not included due to these measures' multicollinearity with the PCL-C.

Group differences on cognitive measures

Figure 1 depicts group differences, and Table 5 shows group differences with and without covariates (branch of service, gender distribution, education, estimated preinjury intelligence, and PCL-C). There are no differences between close blast, non-close blast, and comparison groups on working memory, processing speed, verbal learning, and cognitive flexibility measures that survived Bonferroni correction for family-wise error rate. Findings are the same with and without controlling covariates that differed between groups. Effect sizes of ANOVA models tested, η_p^2, are also reported. For measures that trend towards statistical significance, their corresponding effect sizes are very small.

Discussion

Close proximity to blast, defined as within 30 feet, in a deployed setting was not associated with lower scores within working memory, processing speed, verbal learning, and cognitive

flexibility domains. This was also the case after controlling for posttraumatic stress severity and other demographic variables that may have contributed to findings. On measures where there were trends towards significance, effect sizes were very small. Figure 1 shows that performance of the close blast and non-close blast groups was comparable to that of the comparison group and was within the average range.

Previous meta-analyses, which did not account for distance to blast, reported small to moderate effect sizes acutely after injury between mTBI and comparison groups on cognitive domains including working memory, processing speed, executive functioning, and memory (Belanger et al., 2005; Frencham et al., 2005; Rohling et al., 2011; Schretlen & Shapiro, 2003) that decreased to small or negligible effect sizes beyond three months post injury (Belanger et al., 2005; Dougan et al., 2014; Frencham et al., 2005; Rohling et al., 2011; Schretlen & Shapiro, 2003). Our findings, which are based upon a sample approximately 7 years post deployment, are generally consistent with what others have reported in the literature.

In contrast to the study that prompted analyses of our data (Grande et al., 2018), we did not find lower scores in verbal memory associated with exposure to blast at close range. The effect size reported by Grande and colleagues was very small, with approximately 2% of variance in memory performance accounted for by distance to blast exposure after controlling for education (Grande et al., 2018). We did find a comparable effect size (3–4% that decreased to <1% after controlling for posttraumatic stress symptom severity and demographic confounders) albeit

Table 3. Self-reported symptom and behavioral health questionnaires

	Close blast	Non-close blast	Comparison		
	(n = 47)	(n = 14)	(n = 39)	F or χ^2 (df)	*p*-value
NSI total	27 (14)	30 (16)	11 (11)	17.20 (2, 97)	<.01
PCL-C total	43 (17)	42 (17)	27 (12)	12.67 (2, 97)	<.01
CES-D total	18 (10)	17 (13)	8 (7)	11.72 (2, 97)	<.01
Combat Exposure Scale	25 (7)	19 (11)	7 (6)	57.91 (2, 97)	<.01
HIT6 total	10 (7)	7 (6)	5 (6)	8.18 (2, 97)	<.01

Note: NSI = Neurobehavioral Symptom Inventory. PCL-C = PTSD Checklist, Civilian version. CES-D = Center for Epidemiological Studies, Depression. HIT6 = Headache Impact Test, 6 Items Version.

Table 4. Self-report questionnaires (N = 100). Pearson's correlation coefficients are above the diagonal. *P*-values are below the diagonal

	NSI	PCL-C	CES-D	CES	HIT-6
NSI	–	0.84	0.80	0.39	0.51
PCL-C	<.001	–	0.83	0.43	0.51
CES-D	<.001	<.001	–	0.43	0.49
Combat Exposure Scale (CES)	<.001	<.001	<.001	–	0.42
HIT6	<.001	<.001	<.001	<.001	–

Table 5. Test of group differences on cognitive measures: close-blast vs. non-close-blast vs. control

					Controlling for gender, education, service branch, estimated preinjury IQ, and PCL-C			
	F or χ^2 (df)	*p*-value	η_p^2	Power	F or χ^2 (df)	*p*-value	η_p^2	Power
Working memory			Bonferroni corrected p = .05/5 = .01					
ACT 9 sec delay	1.65 (2, 95)	0.20	0.03	0.34	2.87 (2, 85)	0.06	0.06	0.55
ACT 18 sec delay	1.96 (2, 95)	0.15	0.04	0.40	1.56 (2, 85)	0.22	0.04	0.32
ACT 36 sec delay	2.64 (2, 95)	0.08	0.05	0.51	2.52 (2, 85)	0.09	0.06	0.49
PASAT Trial 1	2.30 (2, 89)	0.11	0.05	0.46	1.96 (2, 79)	0.15	0.05	0.40
PASAT Trial 2	0.54 (2, 89)	0.59	0.01	0.14	0.27 (2, 79)	0.77	<.01	0.09
Processing speed			Bonferroni corrected p = .05/3 = .0167					
SDMT Written	1.02 (2, 97)	0.37	0.02	0.22	0.31 (2, 87)	0.73	<.01	0.10
SDMT Oral	1.94 (2, 97)	0.15	0.04	0.39	1.14 (2, 87)	0.32	0.03	0.25
Trails A time	3.39 (2, 97)	0.04	0.07	0.63	1.45 (2, 87)	0.24	0.03	0.30
Verbal learning			Bonferroni corrected p = .05/2 = .025					
VSRT Total Recall	1.91 (2, 96)	0.15	0.04	0.39	0.003 (2, 86)	1.00	<.01	0.05
VSRT Delayed Recall	1.67 (2, 97)	0.19	0.03	0.34	0.03 (2, 87)	0.97	<.01	0.05
Cognitive Flexibility								
Trails B time	2.28 (2, 97)	0.11	0.05	0.45	0.06 (2, 87)	0.94	<.01	0.06

Note: IQ = Test of Nonverbal Intelligence, 4th Edition. PCL-C = PTSD Checklist, Civilian version. ACT = Auditory Consonant Trigrams. PASAT = Paced Auditory Serial Addition Test. SDMT = Symbol Digit Modality Test. Trails = Trail Making Test. VSRT = Verbal Selective Reminding Test.

statistical significance was not reached, possibly due to a smaller sample size and thus limited statistical power (0.34–0.39) in our study.

Similar to the Grande and colleague's study, this project examined effects of distance to blast regardless of mTBI status. Most participants in our close blast and non-close blast groups had presented with mTBI, but some did not. Due to the heterogeneity of presentations associated with blast exposure in the military, this classification of cases allowed for examination of blast effects in a way that is not as skewed by sampling bias as might be present in a mTBI sample. Presence of mTBI depends on self-report of symptoms, which may be influenced by multiple factors. For example, in a 2007 sample of National Guard deployed to Afghanistan, 9% self-reported mTBI one month before returning from combat zone but 22% of the same sample self-reported mTBI one year after returning from deployment (Polusny et al., 2011). It is unknown

whether this discrepancy in self-reported rates reflects ambiguity regarding symptoms, attribution of sources of symptoms, and/or a desire to present oneself as consistent with a warrior ethos. A mTBI sample may reflect biased sampling. Our decision to classify groups irrespective of mTBI symptoms represents an effort to glean a more objective examination of effects of blast.

The experience of a blast event may be associated with traumatic stress if it occurred within a combat environment, but it may not have such an association if the blast occurred within controlled training environments. Both the close blast and non-close blast groups reported significantly more severe posttraumatic symptoms and combat exposure than the control group (Table 3). The general reduction in effect sizes after controlling for posttraumatic symptom severity (Table 5) is consistent with other studies that evaluated the influence of both PTSD and TBI and showed that PTSD seems to have more impact on cognitive
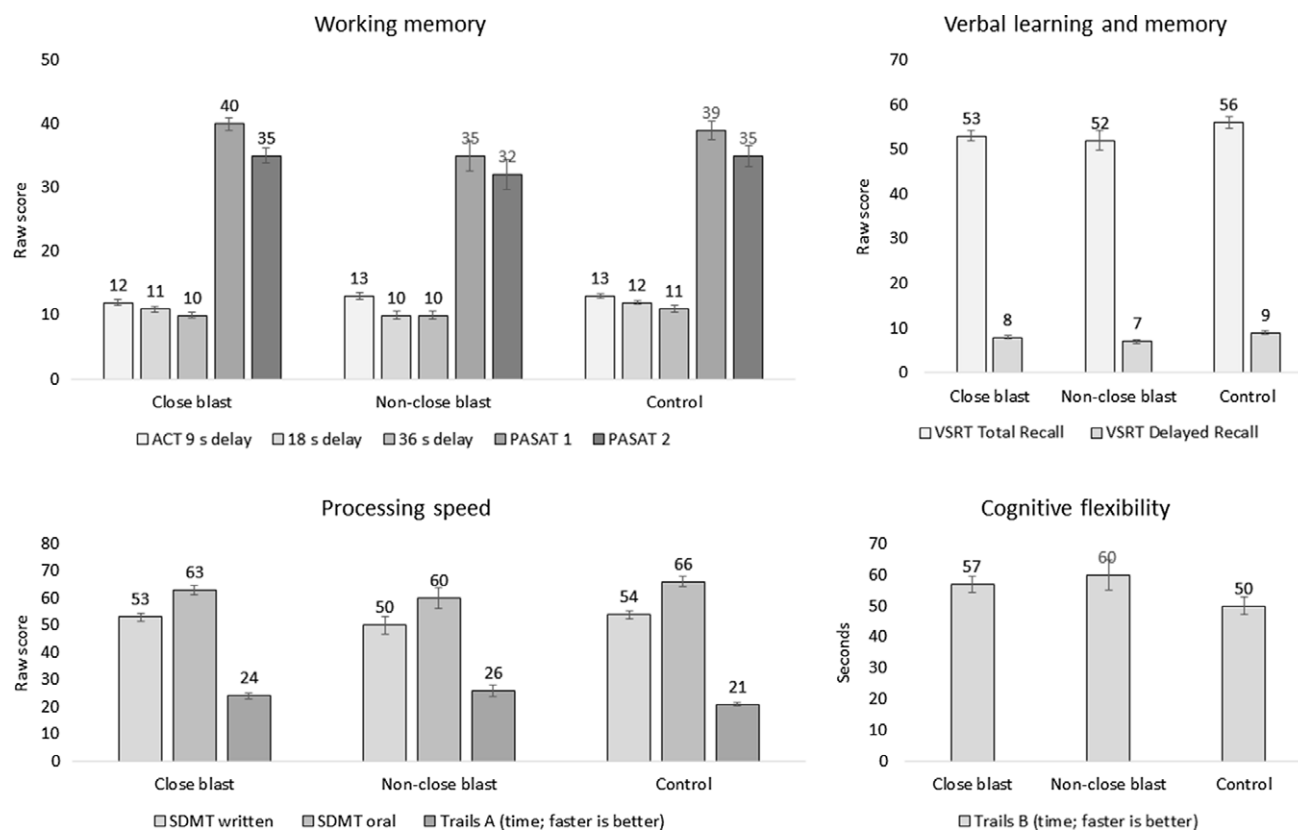
Figure 1. Group differences on measures of cognitive performance. No group difference was significant after controlling for branch of service, gender distribution, education, estimated preinjury intelligence, and PCL-C.

performance than TBI (Hantke et al., 2021; Pagulayan et al., 2018; Vasterling et al., 2018; Vasterling et al., 2012). Nelson and colleagues used structural equation modeling to elucidate the relationship between blast concussion, PTSD severity, and cognitive performance, and found that only PTSD severity directly impacted cognitive performance (Mattson et al., 2019; Nelson et al., 2020). Postconcussive blast indirectly impacted cognitive performance, and its effect was mediated by PTSD severity (Nelson et al., 2020). Thus far this evidence suggests that blast exposure influences cognitive performance through accompanying traumatic stress, and in the absence of traumatic stress, proximity to blast may not convey risk to cognitive sequelae. From the perspective of intervention, these findings suggest that addressing PTSD symptoms may lead to a decrease in cognitive complaints.

This study has several limitations. First, our measure of blast proximity is based on self-report. Recall of events occurring an average of seven years prior may be influenced by factors that affect reconstruction of memory, such as accompanying traumatic events. Second, blast effects on the nervous system may be complex and varied depending on multiple factors, including peak pressure wave severity, accompanying infrasounds, complexity of waves associated with enclosed versus open fields, etc. Distance to blast also does not consider important factors such as whether the context of the blast was controlled, during combat, or whether protective measures were in place. Although we attempted to account for a potential confound by statistically controlling for posttraumatic stress, it remains to be determined by future research what aspects of blast influence cognition and which should be measured and controlled. Third,

heterogeneity of our groups (mix of individuals with and without mTBI symptoms after exposure; close blast group had proportionately more participants who met criteria for mTBI than the non-close blast group) presumably increased within-group variability in the outcome measures, which may have contributed to null group effects. Ideally a longitudinal design that measures cognitive performance before injury and tracks service members through deployment and/or blast exposure would be necessary to answer whether blast characteristics are associated with cognitive change. Finally, the non-close blast group had a very small sample size, which contributed to low statistical power. Despite these limitations, our sample characteristics reflected the cohort of service members who were deployed to OEF/OIF/OND, and for this cohort, close exposure to blast rendered no greater remote cognitive risk than farther blast exposure.

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