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The Relationships Among Premilitary Vocational Aptitude Assessment, Traumatic Brain Injury, and Postdeployment Cognitive Functioning in Combat Veterans[†]

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Abstract

Traumatic brain injury (TBI) in Iraq and Afghanistan war veterans is frequently associated with a variety of complaints, including cognitive problems and posttraumatic stress disorder. In this study, the authors explored the predictive impact of premilitary cognitive abilities on postdeployment cognitive functioning, as mitigated by posttraumatic stress symptoms in a sample of veterans with and without history of TBI. Measures included clinical interview, neuropsychological tests, the PTSD Checklist-Military Version, and the Armed Services Vocational Aptitude Battery. In contrast to history of TBI, premilitary abilities and posttraumatic stress symptoms emerged as significant predictors of postdeployment cognitive deficits.

Keywords: Assessment; Executive functions; Head injury; Traumatic brain injury; Intelligence; Learning and memory; Posttraumatic stress disorder

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Altered mental status is a defining feature of traumatic brain injury (TBI). Symptoms at the time of injury may include loss of consciousness, confusion, amnesia, and/or other focal neurological deficits. Such symptoms are common and expected during the acute recovery phase (Iverson, 2005). Particularly in cases of mild TBI (mTBI), which accounts for ∼82% of all TBIs in military and veteran samples (Defense and Veterans Brain Injury Center, 2013), these symptoms tend to resolve rapidly. Most often, a full recovery takes place within a matter of weeks or months (Iverson, 2005), though cases of enduring neurocognitive complaints have been documented (Zumstein et al., 2011).

Multiple studies have explored the association between TBI and its subsequent impact on neurocognitive domains, such as attention, memory, language, processing speed, and executive function (Bittner & Crowe, 2007; Demery, Larson, Dixit, Bauer, & Perlstein, 2010; Geary, Kraus, Pliskin, & Little, 2010; Hoskison et al., 2009). The most robust findings clearly substantiate a link

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[†] Work was performed across Behavioral Health Carelines in five VA locations in Veterans Integrated Service Network 2 (VA VISN 2): VA Western New York Healthcare System- Buffalo, NY; Albany/ Stratton VA Medical Center-Albany, NY; Canandaigua VA Medical Center-Canandaigua, NY; Bath VA Medical Center-Bath, NY; and Syracuse VA Medical Center-Syracuse, NY.

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between moderate and severe injuries and impaired cognitive status. Furthermore, many studies suggest that the degree of overall cognitive impairment that patients face often corresponds closely with TBI severity level and time since injury, though cognitive profiles do not always uniformly evidence global impairment (DeJong & Donders, 2010). Other evidence suggests further detrimental effects on cognition when multiple mTBIs are sustained (Belanger, Spiegel, & Vanderploeg, 2010).

Studies that focus primarily on cognition after mTBI are less consistent in demonstrating persistent cognitive deficits subsequent to injury. Some authors (e.g., Geary et al., 2010) posit that although typical neuropsychological outcome measures may not yield overt levels of impairment, subtle differences in cognitive performance can become evident among mTBI patients when compared with controls. One study (Cooper et al., 2010) demonstrated only modest reductions in visuospatial and attentional abilities in Afghanistan and Iraq (OEF/OIF) war veterans with co-occurring TBI and burns. However, most veterans in this sample who did underperform on measures still did not fall within clinically impaired ranges, and low observed scores were instead described by the authors more as "inefficiencies rather than impairments" (Cooper et al., 2010, p. 237). Yet other studies suggest that a variety of other personal and demographic factors such as age at time of injury (Senathi-Raja, Ponsford, & Schonberger, 2010), gender (Niemeier, Marwitz, Lesher, & Walker, 2007), evaluation context (Nelson et al., 2010), and level of effort (West, Curtis, Greve, & Bianchini, 2011) may account for partial observed variance in post-TBI cognitive test performance. In contrast to these findings, an Institute of Medicine report from 2009 found little evidence linking mTBI with any objective cognitive deficits outside of the prototypical 6-month recovery window.

Among studies which have examined baseline cognitive abilities, links have been uncovered between pre- and postdeployment functioning. For example, baseline cognitive deficits have been identified as risk factors for the development of posttraumatic stress disorder (PTSD) after combat deployment (Kremen et al., 2007; Marx, Doron-Lamarca, Proctor, & Vasterling, 2009). In related work, others have also shown that cognitive deficits increase risk for multiple other medical, psychiatric, and behavioral disorders, including general anxiety, depression, chronic fatigue, and substance abuse, in addition to PTSD (Binder, Storzbach, Campbell, Rohlman, & Anger, 2001; Gale et al., 2008). Furthermore, TBI has been identified as a risk factor for PTSD (Yurgil et al., 2013), and PTSD has been identified as an independent risk factor for subsequent cognitive impairment (Marx, Brailey, et al., 2009). Though this finding has been demonstrated in both younger (Geuze, Vermetten, de Kloet, Hijman, & Westenberg, 2009) and older adults (Golier, Harvey, Legge, & Yehuda, 2006), at least one study (Vasterling et al., 2006) demonstrated that the effects of PTSD on cognition are reduced after controlling for premorbid cognitive abilities. A body of recent research has identified combat deployment itself—separate from diagnosed psychiatric illness—to be a possible additional predictor of diminished cognitive performance, despite preservation, or enhancement of simple reaction time (Vasterling et al., 2006).

Although the Department of Defense began to administer routine baseline cognitive assessments to deploying military personnel in 2008 (Jaffee & Meyer, 2009), they are not readily available in Department of Veterans Affairs (VA) clinical records and are often not considered in VA's postdeployment neuropsychological exams. VA clinicians are thus often left with an incomplete clinical picture and can most often only form an educated guess as to whether post-TBI cognitive status represents a bona fide change from baseline.

In the interim, one avenue of exploration involves the possibility of using military entrance exam scores as a predictor of postdeployment cognitive functioning. There are several advantages to doing this. First, the Armed Services Vocational Aptitude Battery (ASVAB) measures multiple domains routinely assessed in cognitive examinations, including language, mathematical, and visuospatial skills, and the Armed Forces Qualifying Test (AFQT) subscale has often been used as an estimate of premorbid intelligence (Binder et al., 2001; Franz et al., 2011; Macklin et al., 1998; Orme, Brehm, & Ree, 2001). Second, researchers have in the past used ASVAB scores, specifically the AFQT, to investigate a variety of outcomes in both civilian and military personnel, as well as veterans, as predictors of a wide variety of future vocational, medical, psychiatric, and cognitive outcomes (Binder et al., 2001; Franz et al., 2011; Kremen et al., 2007; Macklin et al., 1998). Furthermore, *all* new military recruits complete the ASVAB prior to enrolling in the armed forces, and thus, this information could potentially become available for veterans seen for clinical assessments.

The present study attempts to further investigate the potential utility of ASVAB scores to account for variance in objective cognitive test scores after deployment. Specifically, we examine the relationship between performance on the ASVAB and cognitive performance in a sample of veterans with and without history of TBI. Further, we investigated the relationship between symptoms of PTSD and cognitive achievement in these groups.

Methods

This examination of the relationship between premilitary vocational aptitude assessment and postdeployment cognitive functioning is one piece of a larger longitudinal study of OEF/OIF veterans. Data were collected from five VA medical centers and one community-based outpatient clinic in the upstate New York Veterans Integrated Services Network (VISN 2). Each site's participation was approved by its local Institutional Review Board (IRB) and Research and Development Committee. All veterans who participated are protected by a National Institute of Mental Health Certificate of Confidentiality.

Participants

The initial sample included 500 OEF/OIF veterans residing in the VA VISN 2 geographic region, which represents urban, suburban, and rural areas across upstate New York. Participants were recruited from a registry of OEF/OIF veterans as well as from clinical referrals for polytrauma or neuropsychology. Informed consent was obtained from each participant after study procedures had been fully explained. No veterans were excluded based on inability to provide informed consent, and no vulnerable participants or participants who required surrogate consent were included. All study participants were compensated for their time and travel.

Measures

Armed Services Vocational Aptitude Battery. The ASVAB is a measure of vocational aptitude designed to screen and classify military applicants. The current version includes 10 subtests across four general domains, namely verbal abilities, math skills, knowledge and application of science and technical skills, and visuospatial abilities. The AFQT, presented as a percentile rank, is a composite score derived from four-specific verbal and math subtests (word knowledge, paragraph comprehension, mathematics knowledge, and arithmetic reasoning). Though mild differences in content exist between computer-adaptive and paper-pencil administrations, AFQT scores across measures are considered equivalent. The ASVAB website (http://official-asvab.com/index.htm) provides additional details on standardization.

Structured diagnostic interview for TBI. A 22-item clinical interview was developed and administered by neuropsychologists at each study site to establish the diagnostic presence and severity of TBI among participants. The interview schedule is available as an appendix to Donnelly and colleagues (2011).

PTSD Checklist-Military Version. The PTSD Checklist-Military Version (PCL-M) is a 17-item self-report survey of PTSD symptoms based on DSM-IV diagnostic criteria (Weathers, Litz, Herman, Huska, & Keane, 1993). Items probe such experiences as disturbing memories and dreams, relational or interpersonal difficulties, and other somatic and cognitive concerns. Although multiple approaches exist to guide interpretation and use of PCL scores (i.e., review of criteria, use of cut scores, or combination of criteria and cut scores; National Center for PTSD, 2012), for the purposes of this study, scores $\geq$50 signified probable PTSD.

Cognitive measures. In addition to the measures described above, participants also completed a comprehensive neuropsychological battery. Measures included the Digit Span and Digit-Symbol Coding subtests from the Wechsler Adult Intelligence Scale—third edition (WAIS-III; Wechsler, 1997); the Trail-Making Test, Parts A and B (TMT A/TMT B; Reitan, 1958); the Design Fluency, Verbal Fluency, and Color-Word Interference Tests from the Delis–Kaplan Executive Functioning System (D-KEFS; Delis, Kaplan, & Kramer, 2001); and the California Verbal Learning Test-II (CVLT-II; Delis, Kramer, Kaplan, & Ober, 2000). Cognitive outcomes were divided into measures of attention (Digit Span, Digit Symbol, and TMT A), executive functioning (TMT B and D-KEFS), and memory (CVLT-II). We also recorded each participant's high school grade-point average (HSGPA; linearly transformed to a 0–100 scale) as an index of academic achievement.

Measures of effort. Two embedded measures of effort were included in this study: Reliable Digit Span (RDS), derived from the WAIS-III Digit Span, and CVLT-II Forced-Choice Recognition (total accuracy; CVLT-II FCR). Inadequate effort (failure) was defined as a score of $<$7 on RDS, or accuracy of $<$93.75% (i.e., $<$15 of 16 items correct) on CVLT-II FCR.

Procedure

Recruitment. OEF/OIF veterans living in the VISN 2 geographic region were sent introductory letters that described the project as well as relevant optout procedures. Veterans who did not return the postcards were contacted by research assistants for telephone screening and enrollment using IRB-approved procedures. Efforts were focused on oversampling women and minorities by identification on the registry and in consultation with the local Minority Affairs Coordinator.

Data collection. After participants completed informed consent procedures, clinical interviews were administered by a licensed psychologist. Interviews were completed within 30 min for most participants. The PCL-M and cognitive measures were then administered by master's level research assistants who had been trained by the investigators and supervised by licensed psychologist investigators at their respective study sites. All interview, self-report, and cognitive data were collected prospectively. Initial ASVAB data were retrieved from the Defense Manpower Data Center of the Department of Defense. High school records were retrieved with permission from participants' educational institutions on a case-by-case basis.

Analysis

Consistent with previous research (Binder, Iverson, & Brooks, 2009), impaired performance on any measure was defined as a standard score of more than 1 *SD* below the normative mean. Participants who evidenced failure on either measure of effort were excluded from analysis. Independent samples *t*-tests and χ^2 analyses explored differences in demographic values and cognitive scores between the TBI and control cohorts. Pearson correlation coefficients are reported to describe the correspondence between predictors and criterion measures. We used multiple regression analyses to investigate the proportion of variance in post-deployment cognitive performance accounted for by AFQT scores, HSGPA, PTSD symptom severity as measured by the PCL-M, and clinically confirmed TBI history. Semi-partial correlations were used to estimate the amount of unique variance explained by each predictor after accounting for the influence of the remaining predictors. Effect sizes were calculated by squaring the semi-partial correlation coefficient (r^2), with magnitude of effects interpreted as small ($r^2 = .01$), medium ($r^2 = .09$), or large ($r^2 = .25$) (Cohen, 1988).

Latent class analysis (LCA) was then utilized to partition the sample of cases with complete predictor data (i.e., ASVAB and HSGPA; $n = 295$) into clusters that explain the association among 10 cognitive measures. The ideal number of classes was selected based on model fit using the Bayesian Information Criterion (BIC) statistic and classification error. Logistic regression was then adopted to model the odds of impaired cognitive function (yes vs. no) using the aforementioned predictors. Odds ratios (ORs) and 95% confidence intervals (CI) were calculated to gauge the likelihood of participants falling into a classification of impaired status based on interpretation of objective tests. Finally, χ^2 automatic interaction detection (CHAID) analysis was used to estimate cut-points at which independent variables best predicted cognitive impairment. Multiple data checks were enabled prior to analyzing data. All analyses were performed with SAS version 9.3 (SAS Institute Inc., Cary, NC) and Latent Gold 4.5 and SI-CHAID (Statistical Innovations Inc., Belmont, MA) software.

Results

Sample Descriptive Statistics

As seen in Table 1, participants were primarily male (89%) and Caucasian (86%) with an average age of 31.6 years ($SD = 8.7$). Most participants were high school graduates (23%) or had completed some college (56%). A substantial minority of participants met diagnostic criteria for PTSD as measured by the PCL-M, though probable PTSD diagnosis was significantly more common in the TBI cohort (58% vs. 27%, $p < .001$). Nearly twice as many veterans in the TBI− cohort were working full time compared with the TBI+ cohort (62% vs. 34%) as substantially more veterans with TBI history reported being unemployed due to subjective or objective disability (34% vs. 16%). Other notable differences were that the TBI+ cohort was significantly younger (29.0 vs. 33.4 years, $p < .001$), more frequently male (99% vs. 83%), and of modestly lower education (i.e., comparatively higher rates of high school-only education with lower rates of postsecondary education) than the TBI− cohort. Veterans with clinician-confirmed TBI typically sustained only one confirmed injury (80%), though a notable subset reported two or more injuries (20%). On average, nearly 3.5 years had passed since veterans with TBI history sustained their respective injuries ($M = 41.5$, range = 0–96 months).

Cognitive Test Results by TBI Status

Several small but significant differences were found between the TBI+ and TBI− cohorts across multiple cognitive domains, though performance on AFQT and other ASVAB subtests were similar. One exception was that veterans with TBI history performed slightly higher than those without on the arithmetic reasoning subtest ($p = .005$).

On average, veterans in the TBI− group outperformed veterans with TBI history on all tests of attention (i.e., Digit Span, Digit-Symbol Coding, and TMT A), though the only significant difference was found on TMT A ($p = .038$). The TBI+ group also scored significantly lower on TMT B ($p = .013$), though performance on other executive measures was similar. More substantial differences were noted in memory performance. Although CVLT-II total learning was equivalent across groups, the TBI− group scored significantly higher on both short- and long-delay recall ($p = .017$ and $<.001$, respectively). Both groups

Table 1. Sample characteristics

	Combined sample ($n = 403$)	TBI+ ($n = 163$)	TBI− ($n = 240$)	p-value
Age: *Mean* ± *SD*	31.6 ± 8.7	29.0 ± 7.0	33.4 ± 9.3	<.001
Male: *n* (%)	359 (89)	161 (99)	198 (83)	<.001
Probable PTSD: *n* (%)	141 (35)	78 (58)	63 (27)	<.001
Education: *n* (%)				.004
Some high school	11(3)	5 (3)	6 (3)	
High school diploma	92 (23)	51 (31)	41 (17)	
Some college/≤2-year degree	227 (56)	88 (54)	139 (58)	
4-year degree	45 (11)	12 (7)	33 (14)	
>4-year degree/graduate degree	28 (7)	7 (4)	21 (9)	
Grade retention- *n* (%)	96 (24)	35 (22)	61 (25)	.362
High school GPA: *Mean* ± *SD*	*77.6 ± 6.8*	*77.0 ± 6.7*	*78 ± 7.0*	.202
Race/ethnicity: *n* (%)				.307
African American	21 (5)	7 (4)	14 (6)	
Asian American	4 (1)	2 (1)	2 (1)	
Caucasian	347 (86)	139 (85)	208 (87)	
Hispanic	16 (4)	6 (4)	10 (4)	
Native American	3 (1)	3 (2)	0 (0)	
Other	6 (4)	6 (4)	5 (2)	
Right handed: *n* (%)	356 (88)	144 (88)	212 (88)	.633
Vocational status: *n* (%)				<.001
Full-time work	204 (51)	56 (34)	148 (62)	
Part-time work	37 (9)	17 (10)	20 (8)	
Full-time student	63 (16)	33 (20)	30 (13)	
Part-time student	3 (1)	0 (0)	3 (1)	
Volunteer	2 (1)	1 (1)	1 (1)	
Unemployed/disabled/none	94 (23)	56 (34)	38 (16)	
1 TBI− *n* (%)	–	131 (80)	–	
≥2 TBIs− *n* (%)	–	32 (20)	–	

Notes: GPA = grade-point average; PCL-M = PTSD Checklist-Military Version; *SD* = standard deviation; TBI = traumatic brain injury; TBI+ = clinician-confirmed TBI history; TBI− = control group. High school GPA is based on a 0−100 scale.

were equally as likely to evidence any level of attentional impairment (32%–33%, $p = .794$), though Veterans with TBI history were more likely to be classified as having any level of executive ($p = .032$) or memory impairment ($p = .002$), based on scoring below a *SD* of -1 on objective measures (Table 2).

Correlations among Predictors and Outcomes Measures

Table 3 provides a full description of inter-item correlations. Statistically significant relationships were generally observed among most predictors and outcome measures. AFQT scores ($|r| = .18–.32$), high school GPA ($|r| = .11–.29$), and PCL-M scores ($|r| = .16–.27$) significantly correlated with most outcome variables, with the exception of the AFQT/TMT A, HSGPA/Digit Span, PCL-M/D-KEFS Design Fluency, and PCL-M/D-KEFS Verbal Fluency pairings. Moderately, strong relationships were observed between the PCL-M and CVLT-II long delay ($r = -.27$), as well as among AFQT and CVLT-II total ($r = .29$) and Digit Span ($r = .32$).

Tables 4 and 5 detail the results of multiple regression analyses using AFQT, high school GPA, PCL-M score, and clinician-confirmed TBI history as predictors of variance in cognitive outcomes. Model parameter estimates (Table 4) show the relative increases or decreases in standard cognitive test scores relative to predictors. With the exception of TMT A, these estimates suggest that higher overall AFQT performance significantly corresponded to cognitive test scores which range from .007 to .152 standard units higher. Similarly, higher HSGPA corresponded to increased performance on TMT A, D-KEFS Color-Word Interference, and Digit-Symbol Coding by .008 to .024 standard units. On the contrary, higher PCL-M scores significantly corresponded to decreased performance on Digit Span, Digit-Symbol Coding, CVLT-II short delay, D-KEFS Color-Word Interference, TMT A, CVLT-II long delay, TMT B, and CVLT-II total by .007–.094 standard units, respectively. Clinician-confirmed TBI history did not correspond to any significant change in cognitive test scores.

As shown in Table 5, AFQT scores accounted for a small-to-moderate effect across all cognitive outcomes. The most pronounced magnitude was seen in D-KEFS Design Fluency scores ($r^2 = .088$), with other effects ranging from $r^2 = .011$ to .073.

Table 2. Comparison of Standardized Cognitive Test results between Veterans with (TBI+) and without TBI (TBI−)

ASVAB[†]	Combined sample ($n = 363$)	TBI+ ($n = 149$)	TBI− ($n = 214$)	p-value
AFQT[a]	64.9 ± 18.9	62.6 ± 19	66.4 ± 19.9	.055
Arithmetic Reasoning[a]	54.7 ± 7.1	55.5 ± 7.0	54.9 ± 7.5	.005
Word Knowledge[a]	53.9 ± 6.1	53.8 ± 5.6	53.9 ± 6.4	.848
Paragraph Comprehension[a]	54.4 ± 6.5	54.3 ± 6.5	54.5 ± 6.5	.825
Mathematics Knowledge[a]	55.4 ± 7.5	54.6 ± 7.2	56.0 ± 7.6	.068
Cognitive tests‡	Combined sample ($n = 393$)	TBI+ ($n = 156$)	TBI− ($n = 237$)	p-value
Tests of attention				
WAIS-III Digit Span[b]	0.1 ± .8	0.0 ± .7	0.2 ± .8	.067
WAIS-III Digit-Symbol Coding[b]	0.0 ± .9	−0.1 ± .8	0.1 ± .9	.161
Trail-Making Test, Part A[b]	−0.1 ± 1.2	−0.3 ± 1.3	0.0 ± 1.1	.038
Tests of Executive Function				
Trail-Making Test, Part B[b]	−0.7 ± 1.7	−1.0 ± 2.0	−0.5 ± 1.6	.013
D-KEFS Design Fluency Composite[b]	0.5 ± .9	0.5 ± .9	0.5 ± .9	.768
D-KEFS Verbal Fluency Category Switching[b]	0.3 ± 1.1	0.3 ± 1.1	0.3 ± 1.1	.574
D-KEFS Color-Word Interference Inhibition/Switching[b]	−0.2 ± 1.0	−0.2 ± 1.0	−0.1 ± 1.0	.748
Tests of memory				
CVLT-II Total Learning[b]	0.1 ± 1.0	0.0 ± 1.0	0.1 ± 1.0	.074
CVLT-II Short-Delay Free Recall[b]	−0.1 ± 1.1	−0.3 ± 1.1	0.0 ± 1.1	.017
CVLT-II Long-Delay Free Recall[b]	−0.3 ± 1.2	−0.5 ± 1.2	−0.1 ± 1.1	<.001
Classification of impairment				
Any attentional impairment: n (%)	126 (32)	51 (33)	75 (32)	.794
Any executive impairment: n (%)	200 (51)	89 (58)	111 (47)	.032
Any memory impairment: n (%)	160 (41)	78 (50)	82 (34)	.002
Any cognitive impairment: n (%)	280 (69)	125 (77)	155 (65)	.010

Notes: CVLT-II = California Verbal Learning Test—second edition; D-KEFS = Delis–Kaplan Executive Function System; WAIS-III = Wechsler Adult Intelligence Scale—third edition.

[a] Mean ASVAB score ± *SD*.

[b] Age-adjusted z-score ± *SD*.

[†] sample size reduced due to missing ASVAB data.

[‡] sample size reduced due to missing cognitive test data.

Table 3. Correlations among predictor and Criterion measures

	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. AFQT	.01	‡.25	‡.18	‡.29	‡.20	‡.28	‡.25	‡.25	‡.30	†−.14	.10	‡.26	‡.32	‡.29
2. Age	–	†.14	*.13	.06	†.16	−.10	−.05	‡.37	.04	‡−.17	*.11	†.15	.07	.02
3. CVLT-II Long Delay		–	‡.79	‡.71	‡.24	.09	‡.26	‡.20	†.15	‡−.27	†.16	‡.24	‡.19	‡.33
4. CVLT-II Short Delay			–	‡.75	‡.21	.10	‡.26	‡.21	†.16	‡−.21	.07	†.16	‡.19	‡.30
5. CVLT-II Total				–	‡.22	‡.19	‡.26	‡.20	*.11	‡−.21	.09	†.15	‡.23	‡.32
6. D-KEFS Color-Word Interference					–	‡.24	‡.22	†.17	‡.19	‡−.21	‡.24	‡.38	‡.25	‡.52
7. D-KEFS Design Fluency						–	‡.21	.08	*.13	−.09	‡.28	‡.33	*.12	‡.33
8. D-KEFS Verbal Fluency							–	*.12	†.15	−.09	†.15	‡.19	*.13	‡.26
9. Education level								–	‡.34	†−.15	.09	*.13	†.14	‡.25
10. High school grade-point average									–	−.10	*.13	†.14	.06	‡.29
11. PTSD Checklist-Military Version score										–	†−.16	‡−.21	‡−.17	‡−.22
12. Trail-Making A											–	‡.60	.06	‡.33
13. Trail-Making B												–	‡.28	‡.35
14. Digit Span													–	†.15
15. Digit Symbol														–

Notes: AFQT = Armed Forces Qualifying Test; CVLT-II = California Verbal Learning Test—second edition; D-KEFS = Delis–Kaplan Executive Function System.

$*p \leq .05$; $^{\dagger}p \leq .01$; $^{\ddagger}p \leq .001$.

Table 4. Model parameter estimates

	N	AFQT	High school GPA	PCL-M score	TBI history
CVLT-II Long Delay	300	.014‡	.006	−.014‡	−.174
CVLT-II Short Delay	300	.007*	.013	−.009*	−.031
CVLT-II Total	300	.152‡	−.020	−.094*	.491
D-KEFS Color Word Interference	296	.008†	.016*	−.011†	.208
D-KEFS Design Fluency	300	.016‡	.005	−.002	.173
D-KEFS Verbal Fluency	300	.013‡	.013	−.004	−.003
Trail-Making A	300	.007	.008*	−.013†	−.104
Trail-Making B	300	.026‡	.002	−.017†	−.097
Digit Span	300	.012‡	−.003	−.007*	.038
Digit Symbol	299	.012‡	.024†	−.009†	.053

Notes: AFQT = Armed Forces Qualifying Test; CVLT-II = California Verbal Learning Test—second edition; D-KEFS = Delis–Kaplan Executive Function System; GPA = grade-point average; PCL-M = PTSD Checklist-Military Version.
*$p \leq .05$; $^{\dagger}p \leq .01$; $^{\ddagger}p \leq .001$. Parameter estimates of continuous variables correspond to change in the outcome per 1-unit increase in the predictor value.

Table 5. Proportion of unique variance in cognitive scores accounted for by predictors

	N	AFQT	High school GPA	PCL-M score	TBI history
CVLT-II Long Delay	300	.045	.001	.034	.005
CVLT-II Short Delay	300	.017	.006	.016	<.001
CVLT-II Total	300	.066	<.001	.020	<.001
D-KEFS Color Word Interference	296	.024	.012	.031	.011
D-KEFS Design Fluency	300	.088	.001	<.001	.008
D-KEFS Verbal Fluency	300	.044	.006	.003	<.001
Trail-Making A	300	.011	.002	.027	.002
Trail-Making B	300	.070	<.001	.024	<.001
Digit Span	300	.073	<.001	.017	<.001
Digit Symbol	299	.054	.030	.022	<.001

Notes: AFQT = Armed Forces Qualifying Test; CVLT-II = California Verbal Learning Test—second edition; D-KEFS = Delis–Kaplan Executive Function System; GPA = grade-point average; PCL-M = PTSD Checklist-Military Version; TBI = traumatic brain injury. Numbers in table represent amount of unique variance explained by a predictor as measured by squared semi-partial correlations.

PCL-M scores accounted for the next most consistent effects, although most were also small ($r^2 = .016–.034$). PCL-M scores did not have a significant bearing upon D-KEFS Design Fluency or Verbal Fluency, however. HSGPA accounted for only a small effect in performance on D-KEFS Color-Word Interference and Digit-Symbol Coding ($r^2 = .012$ and .030, respectively).

Latent Class Analysis

Results from an LCA yielded the best fit for a 5-class model based on 295 participants with complete predictor and outcome data, and who passed on both effort measures (BIC = 7999.65; classification error = 8.0%; 108 participants excluded due to missing predictor data). Classes 1, 2, and 3 (combined $n = 200$, 67.8% of the remaining sample) evidenced normal performance on all cognitive measures. Class 4 ($n = 49$, 16.6% of the subsample) evidenced "memory inefficiency" based on performance on CVLT, although based on typical clinical interpretation, all mean scores from Classes 1 through 4 would likely be interpreted as grossly normal. Class 5, the smallest subsample ($n = 46$, or 15.6% of the subsample) evidenced notable dysfunction on TMT B, as well as subpar performance on TMT A.

Of note, individuals included in this analysis were significantly younger (30.7 vs. 34.1 years old, $p = .004$) and somewhat less educated (evidenced by higher rates of 2-year degrees and incomplete collegiate education, and slightly lower rates of 4-year and postsecondary education), than those who were excluded, though these demographics are generally consistent with those of the original sample described above and depicted in Table 1. No significant differences were found with regard to sex, rates of grade retention, race/ethnicity, handedness, or vocational status. Table 6 compares demographics of individuals included in the LCA vs. those excluded due to missing data points.

Because Classes 1 through 3 were clinically distinct from Classes 4 and 5 (i.e., generally within normal limits vs. impaired on some measures), the subgroups with higher cognitive scores were collapsed into a single group and contrasted to Classes 4 (memory inefficiency) and 5 (executive impairment). This composite cohort then served as the reference group in calculating

Table 6. Sample selection characteristics

	Included ($n = 295$)	Excluded ($n = 108$)	p-value
Age: *Mean* ± *SD*	30.7 ± 7.6	34.1 ± 10.9	.004
Male: n (%)	264 (89)	95 (88)	.663
Education: n (%)			.002
Some high school	7 (2)	4 (4)	
High school diploma	72 (24)	20 (19)	
Some college/≤2-year degree	176 (60)	51 (47)	
4-year degree	25 (8)	20 (19)	
>4-year degree or graduate degree	15 (5)	13 (12)	
Grade retention: n (%)	72 (24)	24 (22)	.648
Race/ethnicity: n (%)			.054
African American	12 (4)	9 (8)	
Asian American	2 (1)	2 (2)	
Caucasian	262 (89)	85 (79)	
Hispanic	9 (3)	7 (6)	
Native American	3 (1)	0 (0)	
Other	6 (2)	5 (5)	
Right handed: n (%)	257 (87)	99 (92)	.441
Vocational status: n (%)			.108
Full-time work	150 (51)	54 (50)	
Part-time work	24 (8)	13 (12)	
Full-time student	51 (17)	12 (11)	
Part-time student	3 (1)	0 (0)	
Volunteer	0 (0)	2 (2)	
Unemployed/disabled/none	67 (23)	27 (25)	

Notes: SD = standard deviation. Table values show a comparison of demographics between participants included and excluded in LCA. Participants were excluded from the latent class and logistic regression analysis if one or more of the outcome and predictor values were missing.

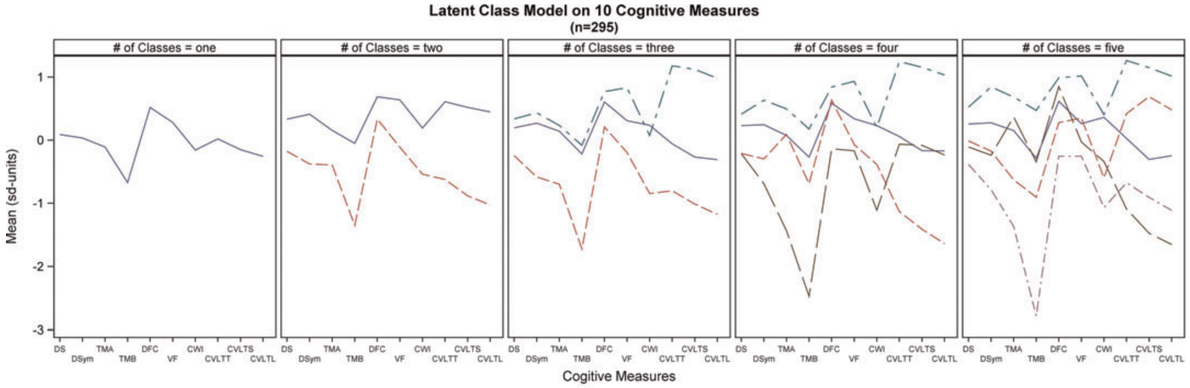
the odds of classification in either the "memory inefficiency" or "executive impairment" subgroups. Higher AFQT scores indeed corresponded to a significantly decreased risk of executive impairment (e.g., an AFQT value of 60 yielded a 29% lower likelihood of executive impairment compared with a score of 50; OR = .71, 95% CI = 0.59–0.87), whereas higher PCL-M scores were significantly associated with a stronger likelihood of executive impairment (e.g., a PCL-M score of 60 yielded a 28% higher likelihood of cognitive impairment than a score of 50; OR = 1.28, 95% CI = 1.03–1.60). Neither AFQT, HSGPA, PCL-M score nor TBI status significantly predicted the memory inefficiencies we observed (Class 4).

CHAID analyses identified cut scores or ranges on the PCL-M and ASVAB based on the likelihood of Class 5 group membership (executive impairment). Whereas PCL-M scores >70 more frequently evidenced executive dysfunction ($p = .019$), AFQT scores >71 least often evidenced executive dysfunction ($p < .001$). Fig. 1 graphically displays the results of the LCA, and Fig. 2 displays predictor ORs and associated 95% CI.

Discussion

Although altered mental status and cognitive complaints are common in the acute phase of TBI recovery, postconcussive symptoms do not tend to persist for more than several weeks. Despite this well-documented fact, many veterans report a host of complaints that may last for several years. It is generally accepted that a variety of conditions may better explain many subjective post-TBI symptoms than TBI itself, particularly when the injury was mild in nature. Common alternative explanations include psychiatric and psychosocial difficulties, chronic pain conditions, and personality characteristics (Cooper et al., 2010; Geuze et al., 2009; Hart, Martelli, & Zasler, 2000; Meares et al., 2011).

Given a general lack of consistent baseline data for many veterans, relatively few studies have explored the link between pre- and postinjury functioning. In this study, we examined the relationship between premilitary factors and postdeployment cognitive functioning, specifically in the form of military entrance exam scores and educational achievement. Though our results showed that veterans with clinician-confirmed history of TBI performed somewhat lower on several cognitive measures than those without history of TBI, these differences were not clearly attributable to TBI history. In fact, confirmed TBI history did not account for *any* statistically significant variation in cognitive outcomes in this sample. Instead, other variables appeared to more accurately predict diminished cognitive performance in this large group of veterans.



Class	Bayesian Information Criterion (BIC)	Number of Parameters (npar)	Classification Error
1	8720.6066	20	0
2	8271.5973	41	0.0595
3	8099.1943	62	0.0579
4	8020.2944	83	0.0701
5	7999.6459	104	0.0801
6	8037.3499	125	0.1009

Fig. 1. Latent class model using predictors to define cognitive impairment. CVLTL = California Verbal Learning Test long-delay free recall; CVLTS = California Verbal Learning Test short-delay free recall; CVLTT = California Verbal Learning Test total; CWI = Delis–Kaplan Executive Functioning System color-word interference; DFC = Delis–Kaplan Executive Functioning System design fluency composite; DS = Digit Span; DSym = Digit Symbol; *SD* = standard deviation; TMA = Trail-Making Test Part A; TMB = Trail Making Test Part B; VF = Delis–Kaplan Executive Functioning System verbal fluency.

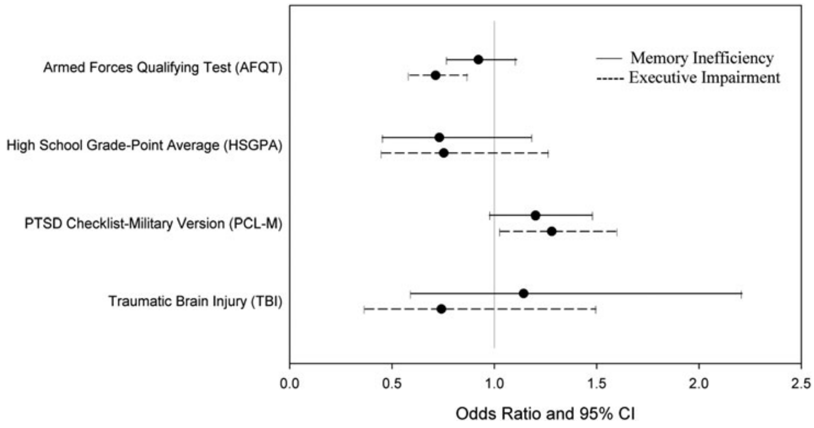


Fig. 2. Multinomial logistic regression of odds of cognitive impairment. ORs and 95% CIs are based on a five-cluster model, which yielded the best overall fit to the data. Figure displays odds of objective cognitive impairment (Classes 4 and 5 derived from LCA) based on confirmed TBI history, and per 10-point change in three continuous predictors. Confidence intervals which overlap a value of 1 are not statistically significant. Each 10-point increase in AFQT scores (OR = .71) corresponds to a 29% decrease in likelihood of executive impairment, whereas each 10-point increase in PCL-M scores (OR = 1.28) corresponds to a 28% greater likelihood of executive impairment.

The effects of probable PTSD symptoms accounted for a small but significant negative effect in memory, attention, and some measures of executive functioning. Educational achievement (as measured by high school GPA) accounted for only a minor degree of variation in cognitive performance. The most noteworthy finding was that, more than all other factors, premilitary cognitive abilities (as approximated by military entrance exam scores) accounted for the most variation in postdeployment cognition at several years postinjury. This small-to-moderate effect was consistently observed across nearly all measures of attention, executive function, and verbal memory (less TMT A). More severe PTSD symptoms, particularly as indicated by PCL-M scores >70, appeared to significantly explain the likelihood of falling into a broad classification of "executive impairment," whereas AFQT scores of 71 or more appeared to have a degree of protective benefit.

Limitations are present in this study and merit mention. Primarily, our definition of cognitive impairment (i.e., 1 *SD* below the mean for any objective test), although rooted in prior work, would not necessarily correspond to a *clinical* interpretation of cognitive impairment. Any single objective test value at or about 1 *SD* below the mean might more likely be interpreted as anywhere from grossly normal to borderline performance, especially given that research (e.g., Binder et al., 2009) has documented that some measure of variation is to be expected in a cognitive battery. In addition, failure on effort measures and missing predictor data resulted in the exclusion of a large portion of the initial sample from our concluding LCA. Although the subsample of individuals included in this analysis was demographically similar to our original combined sample, it is possible that this reduction in sample size may have skewed our results. Indeed, this reduction in sample size effected a detriment to power such that we may have been limited in our ability to detect meaningful effects of other key predictor variables on cognitive outcomes; it remains possible that a larger or more intact sample could have offered an opportunity to detect smaller but still meaningful effects of TBI or achievement (as measured by HSGPA).

Another factor to consider is that, of veterans with history of TBI included in this study, most had sustained their injury(ies) on average >3 years prior to data collection. Therefore, we were not able to detect any cognitive effects that may have been present earlier in their recovery course. Because no independent variable predicted the memory inefficiencies we observed, it is plausible that such inefficiencies could be impacted by a yet unidentified variable, or possibly be attributable to normal within-subjects variation. Lastly, although our investigation focused on deployment-related TBI, studies have been published which demonstrate rates of predeployment TBI in as many as 45% of OEF/OIF veterans (Fortier et al., 2014), and thus this factor remains a potentially uncontrolled influence on the results we observed.

Despite the limitations described above, several strengths are evident as well. Ultimately, the small group of individuals who were identified as having “cognitive impairment” evidenced multiple deficits, and can be viewed as both statistically and clinically distinct from the other subgroups of veterans. Determination of cognitive impairment was based on objective test results and standard scores were calculated based on published normative data. Diagnostic accuracy was enhanced by the administration of a structured clinical interview as opposed to simple self-report of a potential head injury. Rigorous methods were employed to estimate the impact of predictors on outcomes, and to insulate against statistical error. Finally, though time since injury was on one hand a limitation, benefit is retained in the ability to explore cognitive outcomes several years postinjury.

Conclusions

TBI is a signature injury among Iraq and Afghanistan war veterans and is frequently associated with a variety of complaints to include cognitive deficits and PTSD. Our results demonstrated that factors such as premilitary cognitive abilities and PTSD symptom severity were more likely associated with poorer cognitive test performance than mTBI, with premilitary abilities as approximated by the ASVAB accounting for by far the most variation in objective cognitive outcomes in this sample of veterans. These findings constitute an additional piece of feedback that providers may weave into clinical feedback on expectations regarding long-term effects of mTBI and recovery trajectory, and that for many veterans, cognitive abilities can be resilient to both experiences of military stress and mTBI. Future research should continue to explore the evolution of cognitive complaints in veterans with history of TBI, as well as to investigate the potential benefits of active PTSD symptom management in improving attention, executive abilities, and memory.

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Conflict of Interest

The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of the Department of Veterans Affairs or the United States government. Each participating study site was granted approval from both its Institutional Review Board (IRB) and Research and Development (R&D) Committee. Participant responses are protected via a Certificate of Confidentiality granted by the National Institute of Mental Health (NIMH). The authors do not plan to inform participants of the publication of this manuscript.

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