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The Effect of Traumatic Brain Injury (TBI) on Cognitive Performance in a Sample of Active Duty U.S. Military Service Members

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ABSTRACT Introduction: Traumatic brain injury (TBI) is considered a signature injury from the fighting in Iraq and Afghanistan. Since the year 2000, over 370,000 U.S. active duty service members have been diagnosed with TBI. Although prior research has shown that even mild forms of TBI are associated with impaired cognitive performance, it is not clear which facets of cognition (computation, memory, reasoning, etc.) are impacted by injury. Method: In the present study, we compared active duty military volunteers ($n = 88$) with and without TBI on six measures of cognition using the Automated Neuropsychological Assessment Metric software. Results: Healthy volunteers exhibited significantly faster response times on the matching-to-sample, mathematical processing, and second round of simple reaction time tasks and had higher throughput scores on the mathematical processing and the second round of the simple reaction time tasks ($P < 0.05$). Conclusion: In this population, cognitive impairments associated with TBI influenced performance requiring working memory and basic neural processing (speed/efficiency).

INTRODUCTION

The Military Health System defines traumatic brain injury (TBI) as a "traumatically induced structural injury and/or physiological disruption of brain function as a result of an external force that is indicated by new onset or worsening of at least one of the following clinical signs, immediately following the event: any period of loss of or decreased level of consciousness; any loss of memory for events immediately before or after the injury; any alteration in mental state at the time of the injury; neurological deficits that may or may not be transient; inter-cranial lesions".[1] There are five severity classifications of TBI: concussion/mild, moderate, severe, penetrating, and unclassifiable.[1] During FY2016, the Department of Defense invested over $117,000,000 in research and treatment of TBI.[2] Data from the 2017 Defense and Veterans Brain Injury Center indicate that 17,841 service members were diagnosed with a TBI.[3] Studies with active duty and veteran U.S. Military service members have shown that individuals who deploy are at greater risk for being diagnosed with a TBI as compared with those who have not deployed,[4] and common precipitating service-related events leading to TBI include blast injuries,[5–7] falls, and vehicle accidents.[6] Among deployed service members, TBI injuries are most often the result of blasts.[7] A recent study by Regasa and colleagues[7] found that both military service (ie branch, occupation, time between deployments, and time from returning from deployment) and demographics (ie gender and race) significantly predicted deployment-related TBI.

Although prior research has examined the effects of TBI on cognitive performance in U.S. active duty and veteran service members, the findings have been mixed. For example, whereas Vasterling and colleagues[8] found that mild TBI (mTBI) was not associated with performance on measures of memory (visual reproductions), learning (verbal paired associated), and reaction time (RT), Combs and colleagues[9] found that mTBI was associated with poor performance on measures of processing speed and visual attention. Thus, questions remain regarding global effects and isolated effects of blast injuries and whether some cognitive processes are more susceptible to the effects of TBI. At the same time, whereas some evidence suggests that the effects of mTBI on cognitive performance diminish over time,[10] other findings suggest that some cognitive impairments persist.[11] The inconsistencies in the findings of prior research highlight the need for additional research on cognitive impairments associated with TBI in military service members.

The purpose of this article is to examine differences in cognitive performance in a sample of U.S. Military service members with and without a mild or moderate TBI.

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METHODS

Study Population

All volunteers were recruited from Fort Sam Houston, Texas and Brooke Army Medical Center (BAMC) and briefed on the study and completed an informed consent form as required by the BAMC IRB (study # C.2009.117d). Volunteers were also screened by health care providers in the BAMC TBI Clinic to ensure they met the protocol inclusion/exclusion criteria and did not have any conditions that would exclude them from the study (eg, medical contraindications prior to study, such as currently suffering or recuperating from a lower extremity injury or other disorders [other than TBI] that may impact balance [ie, vertigo, vestibular migraine, motion sickness, etc.]), as balance was an outcome measure. However, the balance results are not reported here.

Under a BAMC approved protocol, research volunteers ($n = 88$) read and signed an informed consent form prior to participation. To meet study criteria, volunteers had to:

- Be at least 18 years of age or older
- Not be experiencing hallucinations or delusions
- Be on U.S. military active duty status
- Not have a lower extremity injury or upper extremity injury that would impact outcomes (balance and upper extremity use/speed)
- Not be taking medication that would unduly influence outcome measures (neurocognitive performance and balance)

Volunteers did not receive compensation for their participation.

Questionnaires

Demographic Questionnaire

A self-report measure that included questions about volunteers' background information was given to each volunteer. Information collected included age, gender, time-in-service, number-of-times deployed, and time since last deployment.

Head Injury Survey

A self-report measure that included questions about volunteers' head injury history was given to each volunteer. Information collected included if the volunteer had incurred a head injury prior to military service and/or during deployment (yes/no), and if so, how long the volunteer lost consciousness (less than minute, between one and 20 minutes, or more than 20 minutes) and whether the head injury resulted from a vehicle accident (or other impact injury) or exposure to a blast.

Cognitive Measures

Cognitive tasks were administered via the Automated Neuropsychological Assessment Metric (ANAM) software.[12] All tasks were completed on a personal computer in a controlled laboratory setting. Volunteers completed five subtests in the ANAM suite: (1) two rounds of the simple reaction time (SRT and SRT2) test, (2) the code substitution (CDS) test, (3) the delayed code substitution (CDD) test, (4) the matching to sample (M2S) test, and (5) the mathematical processing (MTH) test. For each test, response times (in milliseconds) and throughput scores (the number of correct responses per unit of available time) were collected. The ANAM software has been shown to have good test-retest reliability.[13]

SRT Test

For the SRT, an asterisk (*) was presented on the screen at varying intervals. The user's task was to press the right mouse button as quickly as possible each time the symbol appeared. The SRT was designed to measure visual-motor processing speed, simple motor speed, and attention.[12]

CDS—Learning

For the CDS, the user's task was to indicate (via keyboard) if a displayed digit-symbol pair matched a defined digit-symbol pair in a displayed table at the top of the screen. This assessment measures visual scanning and perception, attention, associative learning, and RT.[12]

CDD—Memory

For the CDD, participants are presented with digit-symbol pairs and must decide from memory if the pair matches the digit-symbol pairs displayed in the table presented in the CDS taken earlier during the test battery (without the aid of the table). The CDD assesses visual recognition memory.[12]

Matching to Sample

For the M2S, the user was presented with a sample 4×4 grid, with 16 blocks, eight red and eight blue. After a brief study interval, the sample grid was removed and, after another delay, two new patterns were displayed. One of the new patterns was identical to the sample pattern and the other pattern was different than the sample pattern. The volunteers' task was to press one button (eg, "A") to indicate that one pattern was identical or (eg, "B") if the other pattern was identical to the sample pattern. The M2S assesses visual-spatial processing, working memory, and visual short-term recognition memory.[12]

Mathematical Processing

For the MTH, the user was presented with an unsolved math problem of three single-digit numbers and two operations (eg, "$4 + 8 - 5 =$"). Volunteers were to press one button (eg, "A") if the solution to the problem was less than five or a different button (eg, "B") if the solution to the problem was greater than five. The MTH measures concentration, computational skills, and working memory.[12]

TBI Diagnosis

All volunteers participated in an interview conducted by members of the BAMC TBI team (to include physicians,

TABLE I. Means, Standard Deviations, F-values, Significance, and Effect Sizes for Responses to the Demographic Questionnaire Items

	Healthy		TBI				
Demographic	M	SD	M	SD	$F(1, 87)$	P	η_p^2
Age*	39.13	10.15	30.71	7.54	17.66	0.001	0. 17
Time in service*	16.14	8.38	9.08	7.11	16.84	0.001	0.16
No. of deployments	1.64	1.43	2.14	1.38	2.67	0.11	0.03

*$P < 0.01$.

physician's assistants, psychologists, and nurse practitioners). The following criteria for the diagnosis for TBI: a loss of consciousness (less than 30 minutes); memory loss for events immediately preceding (retrograde amnesia) or following the accident (posttraumatic amnesia less than hours); changes in mental state at the time of the injury (dazed, disoriented, and confused); presence of focal neurological deficits; and a Glasgow Coma Scale score $\geq$ 13.[14] Only patients diagnosed with either mild or moderate TBI were included in the present study. For the purpose of this study, mTBI refers to both mild and moderate TBI.

Statistical Analyses

Data analyses were conducted with the IBM SPSS Statistics for Windows (Version 22, Armonk, NY: IBM Corp, Released 2013). Frequencies, descriptive statistics, χ^2, and Analysis of Variance were used to analyze the demographic data and responses on the head injury survey. Separate Analysis of Variances were used to analyze RT's and throughput scores on the ANAM cognitive measures. A significance level of.05 was used for all analyses.

RESULTS

Demographics

Responses to continuously worded items on the demographic questionnaire are presented in Table I. Although the number of deployments was not significantly different between the two groups, healthy volunteers were significantly older and had spent longer time in active duty military service as compared with the volunteers in the TBI group. Among those who deployed ($n = 75$), volunteers in the healthy group reported significantly more years since their last deployment ($M = 4.15$, ± 4.79) as compared with those in the TBI group ($M = 1.27$ years, ± 1.75) ($F(1, 74) = 10.75$, $P < 0.01$, $\eta_p^2 = 0.13$).

There were significantly more male volunteers ($n = 72$) than females ($n = 16$) in the sample, ($\chi^2(1) = 35.64$, $P < 0.001$). There were 38 males in the healthy group, 34 males in the TBI group, 15 females in the healthy group, and one female in the TBI group.

Head Injury Survey

Volunteers in the TBI group reported an average of 200.71 $\pm$ 237.52 days since their head injury. As shown in Table II, among healthy volunteers experiencing a head injury prior to active duty reported losing consciousness for less than a minute and incurring a head injury as a result of a vehicle accident ($P < 0.05$), compared with those in the TBI group. Although loss of consciousness of greater than 20 minutes occurred more often among those incurring a head injury during deployment, the n in each group was extremely small (healthy = 0, TBI = 1).

AUTOMATED NEUROPSYCHOLOGICAL ASSESSMENT METRIC

Response Times

As shown in Table III, significantly faster response times on the M2S, MTH, and SRT2 tasks were observed for the healthy group as compared with the TBI group.

Throughput Scores

Table IV shows that throughput scores on the MTH and SRT2 tasks were significantly higher for the healthy group, compared with the TBI group ($P < 0.05$). Scores on the M2S approached significance ($P = 0.05$), although other measures did not show group differences ($P > 0.05$).

DISCUSSION

In the present study, the cognitive performance of a sample of active duty military service members with and without mild or moderate TBI was compared. Those with a TBI demonstrated diminished performance on tasks requiring attention and concentration; procedural computation; working memory; and neural processing speed/efficiency. Interestingly, these deficiencies are related to one another. An individual's computational difficulties are associated with weaknesses in "attentive behavior and processing speed".[15(p30)] The ability to attend and concentrate (low distractibility and high inhibitory control) facilitates problem-solving through the required mental series of steps.[16] Processing speed facilitates counting and subtracting sums and differences, and pairing of answers in working memory before memory decay sets in.[17]

TABLE II. Responses to Items on the Self-Reported Head Injury Survey, χ^2 Comparisons, and P-values

Item	Healthy	TBI	$\chi^2(1)$	P
Premilitary head injury	9	12	0.43	0.51
Loss of consciousness <1 minute*	10	2	5.33	0.02
Loss of consciousness 1 to 20 minutes	7	4	0.82	0.37
Loss of consciousness >20 minutes	2	1	0.33	0.56
Vehicle accident*	28	14	4.67	0.03
Exposure to blast	2	4	0.67	0.41
Head injury incurred during deployment	12	22	2.94	0.09
Loss of consciousness <1 minute	10	11	0.05	0.83
Loss of consciousness 1 to 20 minutes	3	7	1.60	0.21
Loss of consciousness >20 minutes	0	1	0.00	0.00
Vehicle accident	12	13	0.04	0.84
Exposure to blast	24	25	0.02	0.89

Note. Only data for volunteers that had deployed were analyzed in the head injury incurred during deployment.
$^*P < 0.05$.

TABLE III. Means, Standard Deviations, F-values, Significance Values, and Effect Sizes for Correct Response Times (Milliseconds) for Each Measure of the ANAM Task

	Healthy		TBI				
Measure	M	SD	M	SD	$F(1, 85)$	P	η_p^2
CDS	1268.23	248.06	1288.01	308.29	0.11	0.74	0.00
CDD	1286.42	249.69	1456.31	602.30	3.34	0.07	0.04
M2S*	1538.45	597.82	1879.27	647.28	6.31	0.01	0.07
MTH*	2562.70	800.91	3018.57	819.47	6.59	0.01	0.07
SRT	262.96	37.96	281.66	66.66	2.78	0.10	0.03
SRT2*	278.65	63.98	330.12	129.89	6.06	0.02	0.07

$^*P < 0.05$.

TABLE IV. Means, Standard Deviations, F-values, Significance Values, and Effect Sizes for Throughput Scores on the ANAM Tasks

	Healthy		TBI				
Measure	M	SD	M	SD	$F(1, 85)$	P	η_p^2
CDS	47.75	8.99	47.45	10.96	0.02	0.89	0.00
CDD	119.88	223.13	138.97	350.52	0.10	0.76	0.00
M2S	35.89	11.68	30.84	11.93	3.82	0.05	0.04
MTH*	23.27	7.52	19.94	5.95	4.76	0.03	0.05
SRT	232.20	29.22	222.00	40.59	1.86	0.18	0.02
SRT2*	223.31	37.51	200.20	57.25	5.19	0.03	0.06

$^*P < 0.05$.

That is, quicker processing speed assists with maintaining target memory (working memory) and retrieval of computation results from memory.[18] These results suggest that those with a mild or moderate TBI are likely to have difficulty with any tasks requiring attention, working memory, and processing speed, or any combination thereof, including tasks that were once routine. These findings are consistent with long-term cognitive outcomes previously described, and with longer recovery times for processing speed.[19]

Although response accuracy was similar for TBI and healthy participants on three of the five tasks, participants with mTBI took longer to respond to task items. These findings suggest that individuals with mTBI may benefit from additional time to encode and process information; however, this would only assist if their working memory (including rate of memory decay) is sufficient to hold the current task and solution in memory long enough to respond appropriately.

Bryan and Hernandez[20] found significant differences in the RT of TBI patients relative to healthy controls on the SRT, MTH, and CDS and significant differences in throughput scores on the SRT and CDS measures. Our results support those of Bryan and Hernandez,[20] as volunteers with mTBI in this study also had longer RTs on the MTH task and the second rendering of the SRT task. However, in contrast to the findings of Bryan and Hernandez[20] volunteers with mTBI in this study also had significantly lower throughput scores on the MTH as compared with the healthy group, and no significant group differences were found on the CDS measure. One explanation for the discrepancies in the findings of the two studies is the time since injury. In the Bryan and Hernandez study, participants were tested within 48 hours post injury,[20] although the mean time since injury in our study was over 6 months, with a standard deviation of nearly 8 months. In addition, this study included fewer volunteers than the study conducted by Bryan and Hernandez.[20] A final difference is in the definition of mTBI in which other authors use the abbreviation, mTBI, to refer solely to mTBI, whereas this study grouped those with either a mild or moderate TBI into a single category.

Coldren and colleagues[11] reported that service members who suffered a concussive event had significantly lower throughput scores than healthy individuals on the ANAM SRT, CDS, CDD, and performed equivalently on the MTH when tested within 72 hours of the injury. However, no significant differences were observed 5 or more days after or 10 or more days after the injury. The outcomes of the present study both support and differ from that study, also. Although throughput scores were not significantly different between the groups on four of the six measures, significant group differences were found on the MTH and SRT2. Again, our study was conducted later in the recovery process. These findings appear to suggest that those with a diagnosis of mild to moderate TBI that persists for up to 6 months may demonstrate different cognitive deficits than those assessed immediately after injury. In fact, the volunteers in Coldrens' study would likely not have participated in our study, conducted at a rear echelon recovery facility, at all, as their participants showed no symptoms 10 days post injury.

Although research has suggested the need for baseline data, which were unavailable for participants in this study, Echemendia and colleagues[21] conducted assessments of cognitive change following sports-related mTBI. They examined 223 college athletes who sustained sports-related concussions using both baseline and postinjury data. They concluded that postinjury scores alone can be used to identify the majority of college athletes with clinically meaningful postconcussion cognitive decline.[21]

It should be noted that TBI affects not only service members' cognitive readiness but also their emotional readiness. A recent study with veterans conducted by Elliott and colleagues[22] found that TBI significantly predicted symptoms of posttraumatic stress disorder and lower health-related quality of life. Other studies have shown that among veterans, service-associated TBI was associated with depression, suicidal ideation,[23] and chronic pain.[6, 23] Thus, TBI can pose significant psychological hardship for service members. Future research might benefit from following patients from point-of-injury through their recovery, using a systems perspective including cognitive, emotional, and physical consequences of TBI on military personnel. In addition, documenting the recovery of their functional capabilities at work and home would add considerably to the literature.

LIMITATIONS

One limitation of the current study was that there was a significant time gap between the incursion of volunteers' head injury and testing. A study with the same individuals assessed quickly after injury and periodically throughout the recovery process should assist in further explaining the cognitive effects of mTBI. Prior research has shown that cognitive effects of mTBI tend to be more difficult to identify after significant passages of time, and thus volunteers in this study may also have incurred a more serious (and longer term) injury. A second limitation of the current study was the small sample size, which limited our ability to examine whether the demographic data were significantly associated with group differences in performance. A third limitation is the unavailability of baseline data for research volunteers.

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