MILITARY MEDICINE, 183, 11/12:e580, 2018

Descriptive Analysis of a Baseline Concussion Battery Among U.S. Service Academy Members: Results from the Concussion Assessment, Research, and Education (CARE) Consortium

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ABSTRACT Introduction: The prevalence and possible long-term consequences of concussion remain an increasing concern to the U.S. military, particularly as it pertains to maintaining a medically ready force. Baseline testing is being used both in the civilian and military domains to assess concussion injury and recovery. Accurate interpretation of these baseline assessments requires one to consider other influencing factors not related to concussion. To date, there is limited understanding, especially within the military, of what factors influence normative test performance. Given the significant physical and mental demands placed on service academy members (SAM), and their relatively high risk for concussion, it is important to describe demographics and normative profile of SAMs. Furthermore, the absence of available baseline normative data on female and non-varsity SAMs makes interpretation of post-injury assessments challenging. Understanding how individuals perform at baseline, given their unique individual characteristics (e.g., concussion history, sex, competition level), will inform post-concussion assessment and management. Thus, the primary aim of this manuscript is to characterize the SAM population and determine normative values on a concussion baseline testing battery. Materials and Methods: All data were collected as part of the Concussion Assessment, Research and Education (CARE) Consortium. The baseline test battery included a post-concussion symptom checklist (Sport Concussion Assessment Tool (SCAT), psychological health screening inventory (Brief Symptom Inventory (BSI-18) and neurocognitive evaluation (ImPACT), Balance Error Scoring System (BESS), and Standardized Assessment of Concussion (SAC). Linear regression models were used to examine differences across sexes, competition levels, and varsity contact levels while controlling for academy, freshman status, race, and previous concussion. Zero inflated negative binomial models estimated symptom scores due to the high frequency of zero scores. Results: Significant, but small, sex effects were observed on the ImPACT visual memory task. While, females performed worse than males ($p < 0.0001$, ${}_{p}\eta^2 = 0.01$), these differences were small and not larger than the effects of the covariates. A similar pattern was observed for competition level on the SAC. There was a small, but significant difference across competition level. SAMs participating in varsity athletics did significantly worse on the SAC compared to SAMs participating in club or intramural athletics (all p's < 0.001, $\eta^2 = 0.01$). When examining symptom reporting, males were more than two times as likely to report zero symptoms on the SCAT or BSI-18. Intramural SAMs had the highest number of symptoms and severity compared to varsity SAMs ($p < 0.0001$, Cohen's $d < 0.2$). Contact level was not associated with SCAT or BSI-18 symptoms among varsity SAMs. Notably, the significant differences across competition level on SCAT and BSI-18 were sub-clinical and had small effect sizes. Conclusion: The current analyses provide the first baseline concussion battery normative data among SAMs. While statistically significant differences may be observed on baseline tests, the effect sizes for competition and contact levels are very small, indicating that differences are likely not clinically meaningful at baseline. Identifying baseline differences and significant covariates is important for future concussion-related analyses to inform concussion evaluations for all athlete levels.

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doi: 10.1093/milmed/usx130

INTRODUCTION

Concussion, or mild traumatic brain injury (mTBI), is a functional and microstructural brain injury resulting from direct or indirect forces transmitted to the brain.[1] Estimates suggest that up to 3.8 million sport and recreation-related concussions occur annually.[2] Traumatic brain injury (TBI) has been labeled as the signature injury of recent U.S. military conflicts. Between 2000 and 2006, mTBI hospitalizations rose 108% among service members.[3] At least 285,000 military personnel have been hospitalized with a mTBI since 2000,[4] but this is likely an underestimate as over 50% of military TBIs go unreported,[5] similar to civilian sport-related concussions.[6,7] Notably, non-weapon related TBI hospitalizations were 48% greater than weapon causes, suggesting that the majority of TBIs are unrelated to combat.[3] In fact, between 1997 and 2007, 80% of the mTBIs experienced by active duty U.S. service members occurred within the USA.[8] The majority of mTBIs occur within the continental U.S., which highlights the large number of non-deployed soldiers sustaining mTBIs.[8] These non-deployed mTBI causes include motor vehicle accidents, training exercises, sports and recreation activities, and falls[3], which are similar to those reported by their civilian peers.

Concussion, or mTBI, is considered a transient injury with most individuals' symptoms resolving within 2 wk of injury.[9–11] However, there is growing evidence that concussion, particularly multiple concussions, may be associated with increased risk for long-term mental,[12,13] physical,[14] and cognitive deficits.[15] There is also concern that repetitive concussions and/or head impacts, may be associated with neurodegenerative disorders, for example, chronic traumatic encephalopathy.[16] These long-term studies, however, were based on a select number of males that formerly participated in contact/collision sports, mostly at the professional or varsity collegiate level. There is considerably less data on the natural history of concussion among U.S. service academy members (SAMs), females, and non-varsity athletes.

To date, the majority of sport-related concussion research has been completed at civilian colleges and universities. Few research studies have prospectively examined concussion among military personnel and even fewer among SAMs.[17–21] Only one study has investigated concussions among female SAMs[20] and most SAM-specific studies were conducted at a single service academy.[21] Consequently, there is little concussion research that can be generalized to the entire SAM population.

Other military focused studies have investigated concussion among active duty service members, these studies have focused on combat-related injuries, and the majority of their study populations were enlisted soldiers. A single mTBI study included a subset of officers (17%),[22] reflecting the 19% of officers in the Army, Air Force, and Navy.[23] Additionally, officers and enlisted soldiers have experienced similar increases in mTBIs between 1997 and 2007.[8]

There are notable differences between enlisted soldiers and officers. Given that graduates from U.S. service academies will become officers it is important to classify these differences. First, military officers have higher levels of education than enlisted soldiers.[24] Eighty percent of officers have a bachelor's degree compared to only 7% of enlisted.[24] Women represent a greater proportion of officers (17.6%) compared with enlisted (15.9%) service members.[23] Finally, a smaller proportion of officers (22.8%) identify as a racial minority compared to active duty members (33.2%) .[25] Differences in education, sex, and race across enlisted service members and officers along with limited officer representation in previous studies, highlight the need to investigate the natural history of concussion among SAMs.

The U.S. service academies are unique environments compared with civilian higher education institutions. The education and training environment are common points of stress[26] where SAMs are required to adjust to rigorous physical demands, conformity requirements, and obedience to authority.[27] Reserve Officer's Training Corps (ROTC) members at civilian institutions are not a viable surrogate as they differ from SAMs in terms of socioeconomic status, along with physical and psychological attributes.[28–30] Furthermore, all SAMs are required to participate in an athletic activity, either at the varsity (NCAA), competitive club, or intramural level. No previous investigation has described SAM profiles across sex and competition levels (e.g., varsity, club, intramurals) and many of these characteristics have been shown to influence concussion risk and recovery. For example, higher socioeconomic status correlates with lower symptoms after mTBI[31] and high somatization[32] has been associated with longer recovery duration. Furthermore, female sex has been associated with higher concussion rates[33] and longer recovery times.[34] Thus, identifying baseline patterns in neurocognitive performance and symptom reporting will inform post-concussion evaluations, especially when a baseline evaluation is unavailable.

The primary aim of this manuscript is to characterize the SAM population and establish normative values on a baseline concussion battery across sex, competition level (e.g., varsity, club, intramural, etc.), and varsity contact sport level. Given the possible roles of race, academic year, and academy, these variables were included as covariates. Describing SAMs' demographics, psychological profiles, and neurocognitive characteristics will identify unique SAM characteristics informing concussion assessment and management.

METHODS

Study Design

The National Collegiate Athletic Association (NCAA) and the U.S. Department of Defense (DoD) established a partnership known as the Grand Alliance. The partnership funded the Concussion, Assessment, Research, and Education (CARE) Consortium, a multi-site investigation on the natural history of concussion. An Administrative and Operations Core (AOC), Longitudinal Clinical Study Core (CSC), and Advanced Research

Core (ARC) are directed by the three Consortium PIs [TM, SB, MM] and their teams at the three lead institutions (Indiana University School of Medicine, University of Michigan, and Medical College of Wisconsin, respectively). In addition, the Uniformed Services University of the Health Sciences, in partnership with the lead NCAA sites and U.S. Service Academies, provided support to allow recruitment of all SAM's, not just the NCAA athletes. More detailed information about the CARE Consortium organization has been published previously.[35]

Between 2014 and 2017, 30 sites have joined the CARE consortium under the CSC arm of CARE. The 30 sites include Division I, II, and III schools, from a variety of conferences, and U.S. Service Academies. Prior to data collection at any site, all site personnel were trained on a standardized protocol for preseason baseline testing and post-injury assessments. Site-level institutional review board (IRB) approval and participant consent were obtained. Protocols approved by the IRB of each performance site also underwent review and approval by the DoD Human Research Protections Office.[35]

Within the CARE Consortium, three of the U.S. Services Academies (West Point, Air Force, and Coast Guard) submitted data at the time of the current analysis. Two U.S. Service Academies are Division I institutions (West Point and Air Force) and the third is a Division III institution (Coast Guard). In contrast to the civilian institutions that enrolled only varsity athletes, all cadets were eligible to participate in the CARE study. Detailed CARE study methodology has been published elsewhere.[35]

To best assess clinical differences in concussion outcomes among SAMs, all participants received an annual preseason/baseline assessment that included self-reported demographic information and medical history.[35] The medical history included information about personal and familial medical conditions, concussion history, and psychological history. Additionally, data were collected on household income, years in the primary sport, and race. Next, each SAM completed neurocognitive, neurological, and postural stability examinations along with self-reported psychological and concussion symptom evaluations. Each measure is described below.

Concussion Definition

Based on evidence-based guidelines,[36] concussions were defined as a change in brain function following a force to the head, which may or may not be accompanied by temporary loss of consciousness. While there are subtle differences between the Carney et al[36] and the Concussion in Sport Group definitions,[37] the applications of the definitions are consistent for clinical care and management.[36,37]

At the time of enrollment, SAMs were asked to list all previously diagnosed and/or undiagnosed concussions using the Carney et al[36] definition. Given the focus on baseline characteristics, the current study uses baseline data and thus only self-reported concussion history data.

Participants

All SAMs from the participating U.S. service academies are required to participate in an athletic activity at the intercollegiate varsity, competitive club, or intramural athletics level. Further, all SAMs are required to participate in military training activities, including boxing and self-defense, which also present risk for concussion. Varsity level athletes are NCAA Division I and III athletes and have been categorized into contact, limited-contact, and non-contact sports using exposure groups defined by Rice in 2008.[38] Competitive club athletes are non-NCAA athletes who play on a competitive team and compete in non-NCAA sanctioned intercollegiate competition. Finally, intramural athletes engage in activities where competition occurs between companies at each academy. Classification of activities within competition level has been outlined in Supplementary Table 1.

Measurement Tools

The Sport Concussion Assessment Tool (SCAT3)[39] symptom scale, Brief Symptom Inventory (BSI-18),[40] Standardized Assessment of Concussion (SAC),[41] Balance Error Scoring System (BESS),[42] and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)[43] were the primary assessments administered at baseline. ImPACT and SAC were the primary neurocognitive evaluations used by the academies participating in CARE. The BESS evaluated postural stability, the SCAT3 assessed post-concussive symptoms (number and severity), and the BSI-18 evaluated psychological health symptoms at baseline. Each site received training from the University of Michigan on how to administer each test. Furthermore, additional refreshers were completed at annual consortium-wide meetings and monthly teleconferences.

Immediate Post-Concussion Assessment and Cognitive Testing

While multiple neurocognitive tests were allowable under the CARE protocol,[35] each academy implemented the ImPACT, a computerized neurocognitive assessment that tests verbal memory, visual memory, motor speed, and reaction time performance.[43] When collegiate athletes were tested across a 2-yr interval, ICCs ranged from fair to good for verbal memory (0.46), visual memory (0.65), motor speed (0.74), and reaction time (0.68).[44]

Standardized Assessment of Concussion

The SAC is an acute mental status exam consisting of four domains: orientation, immediate memory, concentration, and delayed recall.[41] The SAC has demonstrated high sensitivity and specificity.[45]

Balance Error Scoring System

The BESS measures postural stability on a firm and foam surface across three stances (i.e., double leg, single leg, and tandem). Scores reflect the number of errors (e.g., losing balance) committed during the 20-s test period.[42] The BESS has been shown to have good test–retest reliability (ICC = 0.87–0.97).[46]

Sport Concussion Assessment Tool

The SCAT3 symptom scale is a standardized assessment for evaluating concussion. The symptom scale contains 22 symptoms and a 7-point Likert scale ranging from "none" to "severe".[39] The SCAT symptom scale has been shown to be fairly reliable at 7 (ICC = 0.62) and 196 (ICC = 0.43) d intervals.[47]

Brief Symptom Inventory

The BSI-18 is an 18-item scale designed to measure psychological distress across four domains: depression, anxiety, somatization, and total distress.[40] Among a TBI sample retested at a median interval of 1 yr, the BSI-18 was shown to have good reliability, with Pearson product moment correlations as follows: total score, 0.66; somatization, 0.67; depression, 0.63; and anxiety, 0.57.[40]

Data Evaluation and Cleaning

SAMs reported demographic, SCAT3, and BSI-18 data on paper forms or by directly entering the information into a customized computer portal (QuesGen Systems Inc.; Burlingame, CA, USA) that contained logic checks to prevent values defined as out of range. SAC and BESS scores were collected on paper and ImPACT data were collected using the ImPACT web platform. All data were entered into the computer portal to create a single database. The data management team reviewed all data and consulted with each academy's research staff to resolve any anomalies. Additionally, to exclude any outliers for the current analyses, the Tukey outlier method was used to detect anomalous values in each primary test assessment. The Tukey method treats any value greater than the 75th percentile plus 1.5 times the interquartile distance or less than the 25th percentile minus 1.5 times the interquartile distance as an outlier.[48] To make the method stricter, three times the interquartile distance was used rather than 1.5 times the interquartile distance. Values falling beyond the range were classified as outliers.

Histograms were generated for the primary outcome variables. ImPACT scores for verbal memory, visual memory, and motor speed were left-tailed skewed. The predominance of high-performing scores would be expected for baseline assessments completed when the SAMs were healthy. ImPACT reaction time performance was right-tailed skewed with a few number of SAMs having slow reaction times. The SAC distribution was left-tailed skewed while the BESS was right-tailed skewed. To normalize the distributions, various data transformations were used. The data transformations are provided in Table I. All statistical analyses were conducted using the transformed values while the tables report the raw untransformed values for interpretation. Individuals who did not identify their competition level (n = 434) or were a non-sport SAM (n = 56, e.g., band member) were excluded from all analyses. All analyses were completed using SAS version 9.4 (Cary, NC, USA).

TABLE I. Data Transformations

Variable	Transformation
SAC	Square Root(20-SAC score)
BESS	Square Root(BESS Total Score)
ImPACT	
Verbal memory	Square Root(100-Verbal Score)
Visual memory	Square Root(100-Visual Score)
Motor speed	Square Root(58.1 – Motor Speed Score)
Reaction time	Log10(Reaction Time Score)

Analysis

Chi-squared statistics were used to assess relationships between competition, contact level, and individual characteristics (e.g., sex). When assessing the number of concussions and time from most recent injury, non-parametric tests were used due to the data being right-tailed skewed. Wilcoxon rank sum test compared the number of concussions across sexes.

Using transformed ImPACT, SAC, and BESS values, linear regression models were built to examine the interaction of sex and competition level across all SAMs. Separate regression models were constructed for each assessment tool. One set of regression models examined the interaction of competition level and sex, while another set examined contact level and sex among varsity level SAMs. Thus, for each dependent variable there was one model for all SAMs examining the interaction of competition level and sex and another model examining only varsity level SAMs to investigate the interaction of contact level and sex. All models controlled for service academy, race, freshman status, and previous concussion(s). Tukey correction for multiple comparisons was used to compare between group differences. Linear regressions also produced the adjusted means and 95% confidence intervals controlling for service academy, race, freshman status, and previous concussion(s). Academy, race, and freshman status were identified as significant covariates from two-way ANOVAs. Concussion history was identified as a significant covariate *a priori* based on previous work showing differences in BESS, SAC, and ImPACT performance between concussed and non-concussed cohorts.[49,50]

Since the BSI-18 and SCAT3 symptom scores were heavily skewed with a high proportion of zeroes, they were assessed using zero inflated binomial (ZINB) models.[51] The ZINB model is carried out in two stages. The first stage assumes that zeroes come from a binary distribution (i.e., two outcomes: zero and not zero) and determines whether there is a statistically significant proportion of zeroes across specified group(s). Next, the zeroes and other values are modeled as a negative binomial distribution:

$$f_{\text{ZINB}}(y; x, z, \beta, \gamma) = \begin{cases} f_{\text{zero}}(0; z, \gamma) + (1 - f_{\text{zero}}(0; z, \gamma)) f_{\text{count}}(0; x, \beta) & \text{if } y = 0 \\ (1 - f_{\text{zero}}(0; z, \gamma)) f_{\text{count}}(y; x, \beta) & \text{if } y \geq 1 \end{cases}$$

Thus, two sets of coefficients are obtained for the independent variables in the model. The first coefficient set describes the proportion of zeroes while the second coefficient set describes the model slopes and calculates the adjusted mean scores. Similar to the linear regression models, separate models were built for all SAMs across all competition levels and varsity level SAMs. The interaction of sex and competition level was examined across all SAMs controlling for academy, freshman status, and previous concussion. In the models examining varsity level SAMs, the interaction of sex and contact level was examined controlling for academy, freshman status, race, and previous concussion. Since females have been shown to report greater symptoms on the SCAT3 and BSI-18,[34,47,52] sex was selected as the zero model parameter for every model.

Due to the large sample size, effect sizes and 95% confidence intervals were calculated in order to determine clinically meaningful differences from statistically significant differences. For the non-parametric *t*-tests, the following formula was used:

$$r = \frac{Z}{\sqrt{N}}$$

where N was the total sample size and Z was the result of the Wilcoxon rank sum test. To interpret the effect sizes, 0.1, 0.3, and 0.5 were used to signify small, medium, and large effect sizes.[53] Partial eta (${}_{p}\eta^2$) was generated to assess effect sizes from linear regression models. For ${}_{p}\eta^2$, 0.01, 0.06, and 0.13 were used as the thresholds of small, medium, and large effect sizes, respectively.[54] Finally, odds ratios generated by ZINB models were converted to Cohen's d effect sizes using the following formula from Chinn[55]:

$$d = \frac{\ln(OR)}{1.81}.$$

For Cohen's d, 0.2, 0.5, and 0.8 were used as the thresholds of small, medium, and large effect sizes, respectively.[53]

RESULTS

Baseline Characteristics

From August 2014 through September 2016, 10,222 SAMs enrolled in the CARE Consortium from three U.S. service academies. Of the 10,222 SAMs who consented and completed a baseline assessment, 9,732 had complete data on competition level and sport and were thus used in the current analyses. For those participants completing subsequent annual baseline assessments, only the baseline evaluation at the time of enrollment was used. SAMs were 19.4 (SD = 1.5) yr old at the time of their first baseline, an average height of 176.96 (SD = 9.45) cm, and mass of 75.8 (SD = 12.95) kg. The majority of SAMs were male (76.1%, $n = 7407$) and freshmen (49.1%, $n = 4768$). The male/female population ratio is reflective of the population of cadets at the academies and the Armed Forces as a whole. Supplementary Table 3 summarizes SAMs by sport and race. Seventy-five percent of SAMs were white. Supplementary Table 4 summarizes academic year by competition level.

TABLE II. Military Activity Level by Sex

	Male	Female	Total
Varsity	2158 (29.13%)	858 (36.90%)	3016 (30.99%)
Contact	1272 (65.84%)	275 (37.67%)	1547 (51.29%)
Limited contact	234 (12.11%)	162 (22.19%)	396 (13.13%)
Non-contact	426 (22.05%)	293 (40.14%)	719 (23.84%)
Club	1105 (14.92%)	468 (20.13%)	1573 (16.16%)
Intramurals	4144 (55.95%)	999 (42.97%)	5143 (52.85%)
Total	7407 (76.10%)	2325 (23.90%)	9732 (100.00%)

Note. 354 missing contact levels for varsity sport cadets.

Table II outlines enrollment by sex and activity level. Overall, more SAMs participated in intramural athletics (52.9%) relative to varsity (31.0%) or club sport activities (16.2%). Of SAMs participating in varsity sports, 51.3% were in contact sports, 13.2% were in limited-contact sports, and 23.8% were in non-contact sports. Males were more likely than females to participate in contact varsity sports (Cochran–Armitage Trend Test $Z = -12.3$, $p < 0.0001$). Supplementary Table 5 summarizes the number of SAMs participating in various varsity sports. Football was the most common sport among varsity SAMs (18.9%, $n = 566$, 26.5% of males) followed by cross country/track (10.1%, $n = 301$), soccer (7.9%, $n = 237$), lacrosse (7.5%, $n = 224$), and baseball (5.4%, $n = 162$). Among female SAMs, the most common varsity sport was soccer (12.4%, $n = 106$).

SAMs reported an average of 0.26 previous concussions and were 3.29 yr (SD = 3.10) removed from their most recent concussion. While male SAMs appear to have reported slightly more prior concussions on average than female SAMs (0.29 vs. 0.24) ($Z = -2.47$, $p = 0.014$, $r = 0.03$), the effect size is negligible. There were significant differences in number of concussions across competition level, contact level, and sex. These differences are described in Table III. However, many of the significant differences had effect sizes below the small threshold ($r = 0.1$). There were two comparisons that had small effect sizes. Varsity SAMs reported significantly more previous concussions at baseline than intramural sport SAMs ($p < 0.001$, $r = 0.1$). Additionally, males reported significantly more concussions at baseline than females within limited contact ($Z = -2.53$, $p = 0.01$, $r = 0.1$) and varsity sports (Table III).

Primary Assessments

Adjusted means and 95% confidence intervals are presented in Tables IV and V. These adjusted means represent performance controlling for previous concussion, sex, race, freshman status,

TABLE III. Concussions by Sex and Military Activity Level

		All Varsity Cadets	Varsity Contact Levels			Club	Intramurals	Total
			Contact	Limited Contact	Non-Contact			
Male	Mean (SD)	0.35 (0.71)[a]	0.42 (0.76)	0.34 (0.69)[a]	0.15 (0.42)	0.23 (0.52)	0.23 (0.54)	0.29 (0.60)[a]
Female	Mean (SD)	0.26 (0.55)	0.38 (0.66)	0.18 (0.40)	0.14 (0.43)	0.25 (0.64)	0.21 (0.54)	0.24 (0.60)
Total	Mean (SD)	0.33 (0.67)[b,c]	0.41 (0.75)[d,e]	0.28 (0.59)[f]	0.15 (0.42)	0.24 (0.56)	0.23 (0.54)	0.26 (0.59)

[a]Significant difference between males and females.
[b]Significant difference between varsity and club cadets.
[c]Significant difference between varsity and intramural cadets.
[d]Significant difference between contact and limited contact.
[e]Significant difference between contact and non-contact.
[f]Significant difference between limited contact and non-contact.

TABLE IV. Linear Regression Adjusted ImPACT Scores (Means and 95% Confidence Intervals)

	Varsity	Contact	Limited	Non-Contact	Club	Intramural
Verbal memory						
Male	92.45 [94.36–90.27]	92.83 [90.00–95.19]	94.86 [92.04–97.06]	92.99 [89.98–95.47]	93.66 [95.44–91.60]	93.16 [94.96–91.10]
Female	93.95 [95.74–91.85]	94.75 [91.95–96.96]	94.69 [91.63–97.06]	94.01 [91.05–96.38]	94.47 [96.23–92.38]	93.90 [95.65–91.86]
Visual memory						
Male	83.44 [80.45–86.17]	82.46 [78.43–86.08]	86.02 [81.84–89.65]	80.59 [76.04–84.66]	85.52 [82.65–88.14]	84.65 [81.80–87.26]
Female	82.00 [78.70–85.03]	83.09 [78.58–87.07]	81.98 [76.95–86.39]	78.23 [73.18–82.76]	82.46 [79.07–85.55]	82.07 [78.88–85.01]
Motor speed						
Male	41.24 [39.77–42.65]	83.53 [81.58–85.38]	85.08 [82.95–87.08]	83.96 [81.90–85.90]	41.92 [40.44–43.34]	41.89 [40.46–43.26]
Female	41.84 [40.30–43.31]	85.30 [83.21–87.26]	84.51 [82.19–86.67]	84.00 [81.83–86.03]	41.92 [40.33–43.44]	41.93 [40.44–43.35]
Reaction time						
Male	0.58 [0.57–0.60]	0.59 [0.54–0.65]	0.56 [0.51–0.63]	0.60 [0.54–0.66]	0.58 [0.56–0.59]	0.57 [0.56–0.59]
Female	0.58 [0.56–0.60]	0.53 [0.48–0.59]	0.52 [0.46–0.57]	0.57 [0.52–0.63]	0.59 [0.57–0.60]	0.58 [0.56–0.60]

Note. Separate linear regression models estimated military sport level (varsity, club, company athletics) and contact sport level (contact, limited, non-contact).

TABLE V. Linear Regression Adjusted SAC and BESS Scores (Means and 95% Confidence Intervals)

	Varsity	Contact	Limited	Non-Contact	Club	Intramural
SAC total						
Male	27.76 [27.24–28.22]	27.38 [26.67–28.01]	27.85 [27.09–28.49]	27.66 [26.93–28.29]	28.33 [27.87–28.73]	28.26 [27.81–28.66]
Female	28.09 [27.58–28.54]	27.73 [26.98–28.38]	28.23 [27.50–28.83]	27.52 [26.73–28.20]	28.22 [27.71–28.66]	28.25 [27.78–28.67]
BESS total						
Male	11.97 [10.71–13.30]	11.77 [10.09–13.57]	11.13 [9.28–13.16]	11.70 [9.92–13.63]	12.18 [10.88–13.56]	11.92 [10.67–13.24]
Female	11.51 [10.20–12.90]	10.65 [8.88–12.58]	12.38 [10.30–14.65]	11.32 [9.47–13.33]	12.06 [10.67–13.53]	11.96 [10.66–13.34]

Note. Separate linear regression models estimated military sport level (varsity, club, company athletics) and contact sport level (contact, limited, non-contact).

academy, and competition level or contact level. For each test, only covariates with at least a small effect size or greater are described below.

The means, standard deviations, medians, and interquartile ranges for each assessment are presented by sport contact level and sex in Supplementary Tables 6a and 7a. Additionally, all significant differences, regardless of effect size are reported in Supplementary Tables 6a and 7a. Supplementary Tables 6b and 7b report the mean differences and associated Cohen's D values.

All SAMs

The raw means and standard deviations for the ImPACT composite scores are presented in Supplementary Table 6a. Linear regression models, controlling for academy, race, freshman status, and previous concussion, significantly estimated verbal memory ($F(12,6492) = 7.37$; $p < 0.0001$), visual memory ($F(12,6498) = 12.26$; $p < 0.0001$), motor speed ($F(121,6496) = 17.31$; $p < 0.0001$), and reaction time ($F(12,6454) = 17.54$; $p < 0.0001$). However, while significant, only 1–3% of the variance in ImPACT scores was explained by each model.

Sex significantly estimated visual memory performance ($p = 0.0001$) with a small effect size ($_{p}\eta^2 = 0.01$). Males had significantly better baseline visual memory performance than females (Supplementary Table 6a). Males score 1.5–3.0 points higher than females on ImPACT visual memory (Table IV). No other main effects of sex were observed on other ImPACT composite scores. While competition level (e.g., varsity, club, or intramural) significantly estimated reaction time, there was a less than small effect size (${}_{p}\eta^2 = 0.001$). Competition level by sex interaction was not significantly associated with baseline ImPACT performance on any subtest. Race was a significant covariate for visual memory (${}_{p}\eta^2 = 0.01$), motor speed (${}_{p}\eta^2 = 0.01$), and reaction time (${}_{p}\eta^2 = 0.01$). Freshman status was significantly associated with motor speed (${}_{p}\eta^2 = 0.01$) and reaction time (${}_{p}\eta^2 = 0.01$).

On the SAC (Supplementary Table 7a), SAMs had an average score of 27.67 (SD = 1.78) and median of 28.00 (IQR: 27.00–29.00). The linear regression model significantly estimated SAC performance ($F(12, 6730) = 21.24$, $p < 0.0001$), explaining 4% of the variance. There was a significant effect for competition level ($p < 0.0001$, ${}_{p}\eta^2 = 0.01$) on SAC performance. Both club and intramural SAMs performed significantly better (all p's < 0.001) than SAMs participating in varsity sports (Supplementary Table 7a). Male SAMs participating in club and intramural sports scored 0.50–0.57 points higher on the SAC than male SAMs participating in varsity sports (Table V). This difference is less among female SAMs with a max difference of 0.16 points (Table V). Academy was the only covariate associated with SAC performance with a small effect size (${}_{p}\eta^2 = 0.01$).

The average number of BESS errors made by SAMs was 13.45 (SD = 6.27). The median number of errors was 12.00 (IQR: 9.00–17.00). While the linear regression model significantly estimated baseline BESS performance ($F(12,6684) = 20.39$, $p < 0.0001$), sex, competition level, and interaction, did not significantly estimate BESS performance beyond the covariates (academy, race, freshman status, and previous concussion) (Supplementary Table 7a). Thus, sex and competition level do not explain BESS performance above and beyond academy, race, freshman status, and previous concussion. Differences were less than a point across sex and competition level (Table V). Academy and freshman status were associated with BESS performance (all ${}_{p}\eta^2 = 0.01$).

Varsity SAMs

The means, standard deviations, medians, and interquartile ranges for ImPACT are presented in Supplementary Table 6a. Linear regression models significantly estimated verbal memory ($F(12,1512) = 3.71$; $p < 0.0001$), visual memory ($F(12, 1513) = 4.95$; $p < 0.0001$), motor speed ($F(12, 1512) = 5.90$; $p < 0.0001$), and reaction time ($F(16, 1494) = 9.98$; $p < 0.0001$). However, while significant, only 3–7% of the variance in ImPACT scores was explained by full regression models.

Sex and contact level were only meaningfully associated with reaction time performance. There was a significant sex by contact level interaction ($p = 0.004$; ${}_{p}\eta^2 = 0.01$). When examining the interaction, male contact SAMs were significantly slower than male limited contact ($p = 0.0012$) or female limited contact ($p = 0.0058$) SAMs. Female non-contact SAMs were significantly slower than male limited contact ($p = 0.0018$) and female limited contact ($p = 0.0033$) SAMs (Supplementary Table 6a). Overall, within each contact level, males participating in varsity athletics demonstrated slower reaction times than females (Table IV). Previous concussion significantly estimated verbal memory performance (${}_{p}\eta^2 = 0.01$). Race was a significant covariate for visual memory (${}_{p}\eta^2 = 0.01$) and reaction time (${}_{p}\eta^2 = 0.01$). Freshman status was significantly associated with motor speed (${}_{p}\eta^2 = 0.03$) and reaction time (${}_{p}\eta^2 = 0.03$). Academy also was significantly associated with reaction time performance (${}_{p}\eta^2 = 0.01$).

Linear regression model significantly estimated SAC ($F(12, 1555) = 7.05$, $p < 0.0001$, $r^2 = 0.05$), and BESS performance ($F(12, 1555) = 7.05$, $p < 0.0001$). However, sex, contact level, and interaction, were not associated with SAC or BESS performance. Across sex and contact levels there was less than a 1.2 point difference on the SAC and BESS (Table V). Academy was significantly associated with SAC and BESS performance (all ${}_{p}\eta^2 = 0.02$), while freshman status was associated with BESS performance (all ${}_{p}\eta^2 = 0.01$).

Symptom Reports

The two SCAT3 scores (i.e., symptom total and severity total) and BSI-18 were analyzed using the ZINB model so conclusions about significant differences can be made for both parts of the model: the proportion of zero values and the scores. Supplementary Table 8 reports the zero probabilities and predicted values for the SCAT3 and BSI-18 symptom scores.

All SAMs

SAMs reported an average of 3.22 (SD = 4.25) symptoms on the SCAT with an average symptom severity of 6.14 (SD = 10.06) (Supplementary Table 7a). Males were more than twice as likely to have a zero score on the SCAT number (OR = 2.86 95% CI: 1.86–4.42; $d = 0.58$) and severity (OR = 2.88 95% CI: 1.83–4.54; d = 0.59) than females. SCAT3 scores were not meaningfully influenced by sex, competition level, or interaction ($d < 0.2$). For both SCAT3 symptom number and severity scores, academy and freshman status had small effect sizes.

On the BSI-18, SAMs had an average score of 2.87 (SD = 5.60). The median BSI-18 score was 0 with an IQR of 0.00–3.00 (Supplementary Table 7a). While females had significantly greater BSI-18 total scores compared with males ($p = 0.02$), the effect size was less than 0.2, indicating that the finding is likely not clinically meaningful. Competition level had a small effect size on BSI-18 total score, with intramural SAMs having 1.45 (95% CI: 1.24–1.70) times greater symptom scores than varsity SAMs ($d = 0.2$). Academy and freshman status had medium and small effect sizes on BSI-18 total scores. Supplementary Table 7 lists all significant findings from ZINB models.

Varsity SAMs

Supplementary Table 7 lists all significant findings from ZINB models among varsity SAMs. Only findings with a small effect size or greater are described below. Males were more than twice as likely to have a SCAT3 symptom score of zero (OR = 2.42 95% CI: 1.09–5.35; $d = 0.49$) and severity score of zero (OR = 2.59 95% CI: 1.15–5.84; $d = 0.53$) when compared to females. Sex, contact level, and interaction did not meaningfully influence SCAT3 scores ($d < 0.2$). Academy had a small effect on SCAT3 symptom and severity score. Freshman status had a small effect on SCAT symptom score and a medium effect on SCAT3 severity score.

Males were no more likely than females to score zero on the BSI-18($p = 0.10$). However, the trend indicated that males were 2.44 (95% CI: 0.85–7.02, $d = 0.49$) times more to report zero BSI-18 symptoms compared to females. Sex, contact level, and the interaction were not meaningfully associated with the BSI-18 symptom scores. Academy and freshman status had medium effect sizes on BSI-18 total scores.

DISCUSSION

The current descriptive analyses found that sex and competition level were significant predictors of baseline concussion assessment performance. Overall, males performed better on the ImPACT visual memory tasks. These findings align with previous studies that found similar baseline differences among traditional NCAA athletes.[56,57] Others have reported no effect of sex on baseline ImPACT results,[58] but this finding is likely due to small sample size. Since this is the first study to examine baseline ImPACT performance across all SAMs, not just intercollegiate varsity SAMs, these sex differences in ImPACT visual memory performance may be the result of the population studied that included all tactical athletes, competing at all levels.

There was no meaningful effect of competition level on any of the ImPACT composite scores. To the best of our knowledge, this is the first comparison of ImPACT performance across competition levels. One previous study did examine the role of varsity athletics on performance at the U.S. Naval Academy[59] and found no difference between varsity and nonvarsity midshipmen. Given the requirement for all SAMs to participate in athletics at the academies, any possible effect of varsity status may be minimized.

Among varsity athletes, there was a small contact level effect on reaction time; limited-contact athletes had better reaction times than contact or non-contact athletes. Using the same contact level designations, Benedict and Parker[60] found a significant sex by contact level interaction on baseline ImPACT verbal memory performance among previously concussed individuals. In the current study, no sex by contact level interaction was observed on any other ImPACT variable. Effect sizes were not reported by Benedict and Parker[60] and cannot be determined by the data presented. The difference in results between the current analyses and Benedict and Parker's[60] results may be due to different sample populations and statistical methods.

Other researchers have compared contact and non-contact sports to examine the effects of repetitive head impacts. McAllister et al[61] findings are somewhat similar to the current study in that contact athletes performed worse on ImPACT reaction compared with a lower contact group. When comparing baseline ImPACT performance among contact (football and ice hockey) and non-contact collegiate athletes, there were significant differences only on visual memory and reaction time performance.[61] The effect size was below the small threshold for visual memory ($d = 0.09$) and small for reaction time performance ($d = 0.29$).[61] Some may argue that the lower performance observed for contact sport athletes may be due to repetitive head impacts. However, that concept is not supported by the findings of the current study as contact and non-contact athletes performed similarly.

Differences in ImPACT scores should be compared with the reliable change indices (RCI) to assess for clinical significance. Using RCIs published by Iverson and colleagues, no group difference observed in the current analysis surpassed the RCIs for 80% and 90% confidence intervals.[43] Therefore, the differences observed in the current study may reflect measurement error and inter-individual variation rather than clinically significant differences.[62] However, since RCIs do not account for regression to the mean, groups with baseline scores that are above or below average should be noted. Groups that score above or below average are more likely to score lower or higher, respectively, because their follow-up test scores are regressing back to the mean.[62] For example, those who score abnormally high on ImPACT tests at baseline may score lower at a post-injury assessment not only due to their concussion but also due to regression to the mean. Consequently, while no ImPACT score differences exceeded RCI thresholds, group differences should be understood to provide context to post-injury performance.

There was a meaningful relationship between competition level and SAC total score. Similar to previous reports,[47,63] varsity SAMs had the lowest SAC baseline scores. Among varsity level athletes, there was no meaningful effect of contact level or sex. This aligns with others reporting no sport, team, or sex differences on SAC scores.[64] The current study adds to the literature by controlling for additional factors (e.g., concussion history), as Zimmer et al[64] did not control for concussion history or race in their analyses. When examining SAC performance it may be important to account for potentially confounding or effect modifying factors.

Baseline BESS errors were not significantly affected by sex, competition level (e.g., varsity, club, or intramural), or contact sport level within varsity SAMs. Some studies have also found no sex effect on BESS performance[64] while others have shown that females have significantly increased baseline BESS errors compared with males.[52] Competition level, rather than contact exposure level, influenced baseline BESS scores while controlling for academy, freshman status, race, and previous concussion. This finding is similar to previous work investigating balance and gait across sport types. Zimmer and colleagues found that women's soccer players had significantly better BESS scores than men's basketball, lacrosse, and football.[64] However, when the authors controlled for height, the effect of sport differences was no longer present, suggesting that height was moderating BESS performance.[64] Similarly, the current analyses found no relationship between sport category and BESS performance even without controlling for height.

Females are more likely to report any symptoms on the SCAT3 or BSI-18. However, this is a non-zero symptom report, and may not be representative of a meaningful clinical symptom burden. Overall, baseline symptom scores are low, with medians ranging from 0 to 3. While females reported more symptoms on the SCAT3 and BSI-18 and have higher symptom severity scores on the SCAT3 than males, the effect was likely not clinically meaningful. This finding is similar to previous baseline symptom studies[52] and conflicts with others finding a meaningful effect of sex on SCAT3 symptoms.[47] The current study may have differed from Chin et al[47] as their sample included high school and college athletes from multiple sites and the analyses did not control for the influence of other covariates like previous concussion or site. While sex may influence symptom reporting, the influence may be minimized when accounting for other covariates such as previous concussion, race, and academy.

Within varsity SAMs, there was no meaningful influence of contact level on SCAT or BSI-18 symptoms. Thus, contact sport exposure does not appear to increase symptom reporting on the SCAT3 or BSI-18 at baseline. While studies have compared baseline neurocognitive performance across contact sport levels,[65,66] this is the first study to examine baseline symptoms in these groups.

The SCAT symptom list was updated in 2016 after the study onset. While the order of symptoms slightly changed, the 22 items remained the same. When the CARE project started the SCAT3 was the most recent edition.[67] In 2016, the International Concussion Consensus group modified the SCAT3 into the SCAT5 to reflect the state of the science and expert review.[67] While the SCAT5 has been modified, the symptom checklist from the SCAT3 and SCAT5 contains the same 22 items.[67] The only difference is that the order of items has slightly changed. "Trouble falling asleep" was item 18 on the SCAT3 and now is item 22 on the SCAT5.[67] Additionally, the SCAT5 symptom checklist contains the question "If 100% is feeling perfectly normal, what percent of normal do you feel".[67] While this question is not asked during the SCAT portion of the CARE questionnaire, it is asked as part of each assessment. Thus, while there are small differences between the SCAT3 and SCAT5 symptom checklists, the CARE protocol has minimized these differences.

There are some differences between SCAT3 and SCAT5 that may inform interpretation of current results relative to future clinical and research exams using SCAT5. For example, the SCAT5 clarifies that the symptom checklist should only be administered when the athlete is at rest.[67] If the SCAT3 is administered while the athlete is not at rest, SCAT3 symptom scores may be higher than SCAT5 symptom scores since physical activity can produce symptoms.[68]

The current analysis is not without limitations. Testing environment, particularly group testing, has been shown to influence neurocognitive performance. Athletes tested in a group setting scored significantly lower on verbal memory, motor speed, and reaction time.[69] While SAMs completed the baseline assessments at individual computer stations, they were tested in proctored groups in order to maximize the allotted testing time. In addition, acute illness or injury has been shown to increase symptom reporting.[70] Illness and injury data were not collected by the CARE protocol so we were unable to control for these variables when assessing symptom reporting. Since the current results identify similar symptom reporting patterns that have been previously observed,[34,47,52] it is unlikely that acute illness or injury had a large impact on baseline symptom reporting. Finally, when examining the coefficients of restitution for each of the linear regression models, the amount of variance explained by the estimators is less than 10%. This leaves much of the variance unexplained. Nevertheless, the large proportion of unexplained variance is similar to previous research investigating ImPACT scores.[71]

CONCLUSION

This is the first investigation to provide normative data for SAMs enrolled at the U.S. service academies. Analyses revealed no evidence that contact sports participation yields worse baseline neurocognitive performance relative to that of non-contact athletes. Overall, the primary variables of interest – sex, competition level, and contact level – had little to no clinically meaningful association with neurocognitive performance or symptom reporting. Notably, race, freshman status, and academy were the covariates that were most commonly associated with performance and symptom reporting.

These results highlight the general uniformity of baseline performance across sex, competition level, and contact level at the U.S. Service Academies. Findings can be used to inform post-injury evaluation for both varsity and non-varsity athletes by establishing normative baseline data. Clinicians performing post-concussion assessment should consider that the influence of sex and contact level may be lower than previously thought. Understanding true baseline differences on a typical concussion assessment battery is critical when using this information to inform diagnosis and return to play decisions.

SUPPLEMENTARY DATA

Supplementary data are available at *Military Medicine* online.

ACKNOWLEDGEMENTS

The authors would also like to thank Jody Harland and Janetta Matesan from Indiana University; Ashley Rettmann from the University of Michigan; Melissa Koschnitzke from the Medical College of Wisconsin; Steven Malvasi, Stephanie Carminati, Sean Roach, and Brian Colsant from the United States Military Academy at West Point; Mike Jarrett, Vibeke Brinck and Bianca Byrne from Quesgen; and Thomas Dompier, Melissa Nicely Baker, and Sara Dalton from the Datalys Center for Sports Injury Research and Prevention and all the service academy members who participated in the CARE study.

FUNDING

This publication was made possible, in part, with support from the Grand Alliance Concussion Assessment, Research, and Education (CARE) Consortium, funded, by the National Collegiate Athletic Association (NCAA) and the Department of Defense (DoD). This work was supported by the Office of the Assistant Secretary of Defense for Health Affairs through the Psychological Health and Traumatic Brain Injury Program under Award NO W81XWH-14-2-0151.

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