Optimizing Concussion Care Seeking

The Influence of Previous Concussion Diagnosis Status on Baseline Assessment Outcomes

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Investigation performed at multiple sites

Background: The prevalence of unreported concussions is high, and undiagnosed concussions can lead to worse postconcussion outcomes. It is not clear how those with a history of undiagnosed concussion perform on subsequent standard concussion baseline assessments.

Purpose: To determine if previous concussion diagnosis status was associated with outcomes on the standard baseline concussion assessment battery.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Concussion Assessment, Research, and Education (CARE) Consortium participants (N = 29,934) self-reported concussion history with diagnosis status and completed standard baseline concussion assessments, including assessments for symptoms, mental status, balance, and neurocognition. Multiple linear regression models were used to estimate mean differences and 95% CIs among concussion history groups (no concussion history [n = 23,037; 77.0%], all previous concussions diagnosed [n = 5315; 17.8%], ≥1 previous concussions undiagnosed [n = 1582; 5.3%]) at baseline for all outcomes except symptom severity and Brief Symptom Inventory–18 (BSI-18) score, in which negative binomial models were used to calculate incidence rate ratios (IRRs). All models were adjusted for sex, race, ethnicity, sport contact level, and concussion count. Mean differences with 95% CIs excluding 0.00 and at least a small effect size (≥0.20), and those IRRs with 95% CIs excluding 1.00 and at least a small association (IRR, ≥1.10) were considered significant.

Results: The ≥1 previous concussions undiagnosed group reported significantly greater symptom severity scores (IRR, ≥1.38) and BSI-18 (IRR, ≥1.31) scores relative to the no concussion history and all previous concussions diagnosed groups. The ≥1 previous concussions undiagnosed group performed significantly worse on 6 neurocognitive assessments while performing better on only 2 compared with the no concussion history and all previous concussions diagnosed groups. There were no between-group differences on mental status or balance assessments.

Conclusion: An undiagnosed concussion history was associated with worse clinical indicators at future baseline assessments. Individuals reporting ≥1 previous undiagnosed concussions exhibited worse baseline clinical indicators. This may suggest that concussion-related harm may be exacerbated when injuries are not diagnosed.

Keywords: concussion disclosure; concussion reporting; mild traumatic brain injury; concussion diagnosis

Concussion is a common injury in athletics and the military. Many factors influence concussion rates in athletics, such as competition level (high school or college), sex, and sport.[48] For college athletes, sports such as women's soccer and men's ice hockey, among others, have high concussion rates. In women's soccer, 5.2% of all injuries are concussions,[19] while 10.1% of all men's ice hockey injuries are concussions.[39] In the military, between 15%[29] and 23%[59] of servicemembers report sustaining a traumatic brain injury, of which the majority (>80%)[18] are classified as mild traumatic brain injuries, or concussions. Unique from orthopaedic injuries, concussion treatment relies heavily on symptom self-report for both initial diagnosis and effective clinical care. Proper concussion management commonly revolves around assessments of neurologic function, symptom report, neurocognition, and balance.[6,43] Because of the reliance on self-report, among other factors, to initiate clinical evaluation and injury management, the true rate of concussion within athletic and military

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settings remains unclear, as each group may perceive repercussions to reporting their concussions.[23,60]

Timely concussion identification and diagnosis is critical for clinicians to properly treat a concussion.[2,4] When symptoms are not reported, the injury may go undiagnosed and the injured person continues activities without medical care or accommodations, prolonging injury recovery.[2,21,36] Unfortunately, the prevalence of undiagnosed concussions is high. In a sample of US Army service members, only 52% of soldiers who sustained a concussion reported the injury.[22] Similar unreported concussion frequencies have been described in youth ice hockey players,[63] high school athletes,[42] professional rugby union players,[24] and military service academy cadets.[53] While numerous efforts are ongoing to increase concussion reporting,[34,37,58] understanding potential negative effects associated with undiagnosed concussions[23] is important given the large number of athletes and servicemembers experiencing these injuries. Further, quantifying the adverse effect of undiagnosed concussion may highlight the importance of interventions to facilitate early identification of injured individuals.

Individuals who sustain an undiagnosed concussion may be at risk for worse concussion-related outcomes. Those with a history of undiagnosed concussions were more likely to have recurrent symptoms after physical activity resumption after sustaining a subsequent concussion,[47] had greater symptom severity scores, and were more likely to lose consciousness after subsequent concussion than those without previously undiagnosed concussions.[46] These data imply that concussions that are improperly managed due to being undiagnosed may result in subtle, subclinical impairments that are magnified by a subsequent brain injury. However, it is unknown if the harm caused by undiagnosed concussions could be detectable through concussion assessment battery performance in the absence of subsequent concussions. In other words, do those with a history of undiagnosed concussions perform the same on the standard concussion assessment battery as those with no concussion history or a history of only diagnosed concussions? The answer to this question may have clinical implications for interpreting baseline concussion assessment data and may increase our understanding of potential lingering or subclinical deficits from unreported and undiagnosed concussions.

The objective of this study was to determine if previous concussion diagnosis status (no concussion history, all previous concussions diagnosed, ≥1 previous concussions undiagnosed) was associated with outcomes on a standard baseline concussion assessment battery. We explored this objective using a large sample of nearly 30,000 college athlete and military academy cadet baseline assessments while controlling for known factors that influence concussion care seeking: sex, race, ethnicity, sport contact level, and number of previous concussions.[32,61,62] We hypothesized that those with a history of at least 1 undiagnosed concussion would have poorer baseline concussion assessment battery performance than those with a history of only diagnosed concussions or no concussion history.

METHODS

Participants

We used data from the Concussion Assessment, Research, and Education (CARE) Consortium. Participants included college varsity athletes and military cadets from 30 institutions. CARE Consortium methods have been previously described in depth,[7] with specific details relevant to this study provided below.

Each participant completed a baseline demographic questionnaire, a symptom checklist, the Brief Symptom Inventory–18 (BSI-18), a mental status examination, a balance assessment, and a computerized neurocognitive assessment before beginning their respective sport season (for athletes) or military training (for cadets). Although some participants completed multiple baseline assessments,

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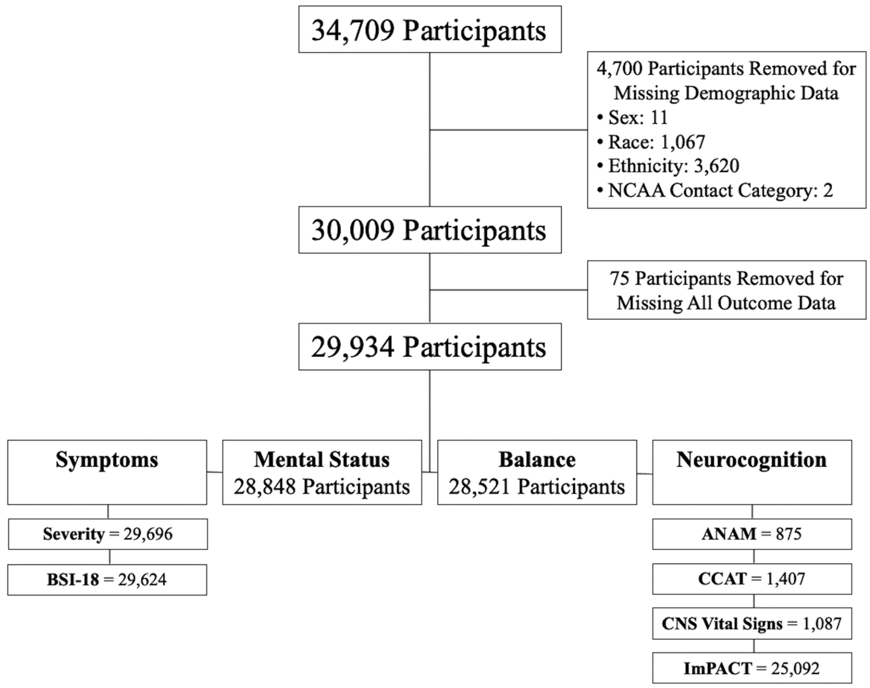

Figure 1. Participants available for each outcome measure. ANAM, Automated Neuropsychological Assessment Metrics; BSI-18, Brief Symptom Inventory–18; CCAT, Computerized Cognitive Assessment Tool; ImPACT, Immediate Post-concussion Assessment and Cognitive Testing; NCAA, National Collegiate Athletic Association.

only the assessment taken at the time of enrollment was used in this study. Participants were included if they had valid baseline data for at least 1 of the outcome variables and reported sex, race, ethnicity, and sport category. Figure 1 details the final sample for each analysis. All participants provided informed consent. The study was approved by each site's local institutional review board and the United States Army Human Research Protection Office.

Demographics and Concussion Diagnosis Status

The Demographics and Personal and Family Medical History unique case report form was used to capture demographic factors and concussion history.[7] Pertinent demographics included sex, race, and ethnicity. Participants were categorized based on the contact level associated with their sport (contact, limited contact, noncontact)[54] or a fourth categorization for non–National Collegiate Athletic Association (NCAA) military service academy cadets.

Concussion history and diagnosis status were determined using the Personal and Family Medical History case report form.[7] Participants first read the definition of concussion: "A change in brain function following a force to the head, which may be accompanied by temporary loss of consciousness, but is identified in awake individuals with measures of neurologic and cognitive dysfunction." This definition was accompanied by a list of common symptoms and was held standard across CARE Consortium sites. Additionally, participants reviewed important distinctions that concussions can occur without loss of consciousness and can be what may be termed, "getting your 'bell rung'" or "clearing the cobwebs." Participants then selected "yes" or "no" as to whether they ever had a concussion. If "yes" was selected, participants reported their total number of previous concussions.

The main exposure of interest in this study, concussion diagnosis status, was based on additional self-reported information provided regarding whether each previous concussion was diagnosed or undiagnosed. Concussion diagnosis status was binned into 3 groups: (1) no concussion history, (2) all previous concussions diagnosed, and (3) $\geq$1 previous concussions undiagnosed. The no concussion history group consisted of those participants responding that they had no concussion history. The all previous concussions diagnosed group consisted of those participants responding that (1) they had at least 1 concussion and (2) all concussions were diagnosed. The $\geq$1 previous concussions undiagnosed group consisted of those participants responding that (1) they had at least 1 concussion and (2) not all concussions were diagnosed (ie, at least 1 concussion was undiagnosed).

Outcome Measures

Symptoms

The Sport Concussion Assessment Tool 3 (SCAT3) symptom checklist contains a list of 22 symptoms.[44] Participants rated each symptom on a 0 to 6 scale, with 0 indicating the symptom was not present and 6 indicating the symptom was as severe as possible. The severity scores were summed across all symptoms, resulting in a symptom severity composite score, with higher scores indicating more severe symptoms. The total number of symptoms was also recorded by summing the number of symptoms that were endorsed above a score of 0. The BSI-18 contains 18 items and requires the participants to rate their level of distress over the past 7 days using a 0 to 4 scale, with 0 indicating not at all and 4 indicating extremely often.[45] The ratings were summed, resulting in a single BSI-18 composite score.

Mental Status

The Standardized Assessment of Concussion (SAC) is a brief assessment that includes measures of orientation, immediate memory, concentration, and delayed recall.[40] Scores across the measures were summed such that a single composite score was calculated, with a value of 30 representing maximum performance (higher score indicates better performance).

Balance

The Balance Error Scoring System (BESS) required participants to perform six 20-second balance trials, 3 on a firm surface and 3 on a foam surface.[28] There were 3 foot conditions: feet together, single-leg stance on the nondominant leg, and tandem stance (heel to toe) with the dominant foot in front. Participants closed their eyes and placed their hands on their hips for each trial and were asked to maintain their best balance for the 20-second period. Trained raters noted the total number of balance errors and summed them, resulting in a single BESS composite score, with a higher score representing worse balance performance.

Neurocognition

Four computerized neurocognitive assessments were used across the CARE Consortium: Immediate Post-concussion Assessment and Cognitive Testing (ImPACT; 25 sites), CNS Vital Signs (2 sites), the Automated Neuropsychological Assessment Metrics (ANAM; 2 sites), and the Cogstate Computerized Cognitive Assessment Tool (CCAT; 1 site).[7] Each of these tests has been described in detail elsewhere. ImPACT generates composite scores to quantify performance in the following domains and takes approximately 20 minutes to complete: verbal memory, visual memory, visual motor speed, and reaction time.[38] CNS Vital Signs takes approximately 25 minutes to complete, generating outcomes in the following domains (raw domain scores were analyzed here): verbal memory, visual memory, psychomotor speed, reaction time, complex attention, cognitive flexibility, and processing speed.[27] The ANAM, which takes about 20 minutes to complete, produces throughput scores for the following assessments: simple reaction time (tested twice during the battery), code substitution, procedural reaction time, matching to sample, and delayed code substitution. Throughput scores are the product of speed and accuracy and represent overall efficiency on each assessment.[57] The CCAT is a 15-minute test that reports outcome measures in the following domains: processing speed, attention, learning, working memory speed, and working memory accuracy.[12]

Statistical Analysis

Data were analyzed using SAS software (Version 9.4; SAS Institute Inc). Frequencies and distributions were computed for concussion history and demographic data. For outcome measures, means with standard deviations were calculated.

Before analyses, correlations were explored between outcomes in the same category (ie, within symptoms, neurocognition, etc). When ≥2 outcomes were highly correlated ($r >$ 0.85), one of the outcomes was discarded before the analyses were conducted. Using this method, we removed SCAT total symptom number along with the CNS Vital Signs executive function domain. Comparisons across previous concussion diagnosis status categories were conducted using multivariable models. All outcome measures featured distributions satisfying linear regression analyses,[35] except for SCAT symptom severity score and BSI-18 composite score, which were skewed right and exhibited overdispersion. Thus, for all outcomes except for SCAT symptom severity score and BSI-18, concussion history groups were compared via multiple linear regression models that estimated mean differences and 95% CIs. For SCAT symptom severity score and BSI-18, concussion history groups were compared via negative binomial models[1] that estimated incidence rate ratios (IRRs) and 95% CIs. All models were adjusted for sex (male vs female), race (White vs African American, Asian/Pacific Islander, other), ethnicity (Hispanic vs non-Hispanic), sport contact level (contact sport vs limited contact sport vs noncontact sport vs non-NCAA military service cadet), concussion count (discrete variable), and clustering by study site. These adjustments were made to account for known variables that affect concussion care-seeking behaviors and/or performance on outcomes measured in this study.[32,61,62] Further, growing evidence suggests racial and ethnic differences related to patient care after concussion and traumatic brain injury in civilian and military populations.[11,16,55] We considered accounting for education level, but given the relatively homogeneous sample (ie, all participants were enrolled in a university), we did not include education as a covariate.

From these models, "clinical meaningfulness" was also assessed through examining effect sizes. For multiple linear regression models, adjusted effect sizes were calculated by taking the differences of the group means and dividing them by the overall standard deviation of the score. The results highlight those mean differences with 95% CIs excluding 0.00 and at least a small effect size (ie, ≥0.20),[56] and those IRRs with 95% CIs excluding 1.00 and at least a small association (ie, IRR, ≥1.10).[30]

RESULTS

A total of 23,037 (77.0%) participants reported no concussion history, while 5315 (17.8%) reported that all their concussions were diagnosed, and 1582 (5.3%) reported at least 1 concussion was undiagnosed. Table 1 contains the demographic breakdown for all 29,934 participants.

TABLE 1
Characteristics of 29,934 Participants, by Previous Concussion Diagnosis Status: CARE Consortium, 2014-2018[a]

Characteristic	No Concussion History (n = 23,037; 77.0%)	All Previous Concussions Diagnosed (n = 5315; 17.8%)	≥1 Previous Concussions Undiagnosed (n = 1582; 5.3%)
Sex			
Female	8822 (38.3)	2021 (38.0)	498 (31.5)
Male	14,215 (61.7)	3294 (62.0)	1084 (68.5)
Race			
White	17,416 (75.6)	4135 (77.8)	1218 (77.0)
African American	2518 (10.9)	602 (11.3)	152 (9.6)
Asian/Pacific Islander	1306 (5.7)	149 (2.8)	50 (3.2)
Asian	1173 (5.1)	114 (2.1)	40 (2.5)
Hawaiian/Pacific Islander	133 (0.6)	35 (0.7)	10 (0.6)
Other[b]	1797 (7.8)	429 (8.1)	162 (10.2)
Indian/Alaskan	117 (0.5)	23 (0.4)	14 (0.9)
Multiracial	1680 (7.3)	406 (7.6)	148 (9.4)
Ethnicity			
Hispanic	2027 (8.8)	408 (7.7)	125 (7.9)
Non-Hispanic	21,010 (91.2)	4907 (92.3)	1457 (92.1)
Sport played			
Contact sport	6431 (27.9)	2566 (48.3)	606 (38.3)
Limited contact sport	5167 (22.4)	1014 (19.1)	312 (19.7)
Noncontact sport	3919 (17.0)	554 (10.4)	190 (12.0)
Non-NCAA military cadet	7520 (32.6)	1181 (22.2)	474 (30.0)
Concussion count history			
0	23,037 (100.0)	0 (0.0)	0 (0.0)
1	0 (0.0)	4244 (79.8)	1015 (64.2)
2	0 (0.0)	827 (15.6)	363 (23.0)
≥3	0 (0.0)	244 (4.6)	204 (12.9)

[a]Data are presented as n (%). CARE, Concussion Assessment, Research, and Education; NCAA, National Collegiate Athletic Association.
[b]Race categories are collapsed because of sample size restrictions.

All results reported here reflect our definition of clinical meaningfulness described in Methods (mean differences with 95% CIs excluding 0.00 and at least a small effect size, and those IRRs with 95% CIs excluding 1.00 and at least a small association). Tables 2 and 3 provide descriptive information and between-group comparisons for all outcomes and highlight all statistically significant findings along with clinically meaningful findings.

The ≥1 previous concussions undiagnosed group reported significantly greater symptom scores and BSI-18 composite scores relative to both of the other groups, while the no concussion history and all previous concussions diagnosed groups were not different. When comparing neurocognitive outcomes between the no concussion history and the all previous concussions diagnosed groups, only ANAM matching to sample and simple reaction time test 2 were different at baseline, with the all previous concussions diagnosed group performing worse on both outcomes than the no concussion history group. However, the undiagnosed group performed significantly worse relative to the no concussion history and all previous concussions diagnosed groups on 6 comparisons (CNS Vital Signs: visual memory [worse than both groups], processing speed, reaction time; ANAM: simple reaction time test 1, procedural reaction time) while only performing better on 2 (ANAM: matching to sample; CCAT: learning). There were no between-group differences on mental status or balance assessments (Table 3).

DISCUSSION

Proper concussion management relies on clinicians being aware of the injury and receiving accurate and timely symptom information from the patient. We observed greater baseline symptom severity and BSI-18 scores and numerous worse neurocognitive outcomes in those who reported at least 1 undiagnosed concussion as compared with those who reported a history of only diagnosed concussions or no concussion history. These findings may provide insight into subtle lingering concussion-related deficiencies in those who sustain a concussion that goes undiagnosed.

We observed significantly higher symptom severity scores at baseline, with those having not reported ≥1 previous concussions reporting 1 point higher on average compared with those who reported no concussion history and those who reported all previous concussions. However, when comparing those with no concussion to those who reported all previous concussions, there were no differences in symptom severity. Thus, those who had experienced concussions—but reported all of them—showed a more

TABLE 2
Descriptive Statistics for Concussion Baseline Assessment Outcomes Among 29,934 Participants, by Previous Concussion Diagnosis Status: CARE Consortium, 2014-2018[a]

Outcome	No Concussion History	All Previous Concussions Diagnosed	≥1 Previous Concussions Undiagnosed
Symptoms			
SCAT symptom severity[b] (n = 29,696)	2 (0-6)	2 (0-6)	3 (0-10)
BSI-18[b] (n = 29,626)	0 (0-3)	0 (0-3)	1 (0-5)
Mental status (n = 28,848)			
SAC total score	27.5 (1.9)	27.5 (1.9)	27.4 (1.9)
Balance (n = 28,521)			
BESS total error score	13.7 (6.4)	13.3 (6.3)	13.7 (6.5)
Neurocognition (ImPACT[c]; n = 25,092)			
Verbal memory	88.2 (10.0)	89 (10.1)	88.1 (9.9)
Visual memory	78.9 (12.9)	79.5 (12.9)	79.4 (13.2)
Visual motor speed	41.6 (6.4)	42.2 (6.4)	41.9 (6.2)
Reaction time	0.6 (0.1)	0.6 (0.1)	0.6 (0.1)
Neurocognition (CNS Vital Signs[d]; n = 1087)			
Verbal memory	52.2 (5.0)	52.2 (4.9)	52 (4.2)
Visual memory	47.5 (5.2)	47.6 (5.3)	45.9 (5.6)
Psychomotor speed	187.7 (21.8)	188.6 (19.7)	183.9 (19.8)
Reaction time	641.6 (86.8)	631 (80.5)	655.1 (89.2)
Complex attention	10.1 (14.1)	9.2 (7.6)	9.8 (7.8)
Cognitive flexibility	45.7 (9.7)	46.5 (9.2)	45.9 (12.3)
Processing speed	63.6 (11.0)	64.4 (12.7)	61.8 (11.6)
Neurocognition (ANAM[e]; n = 875)			
Simple reaction time test 1	219.4 (29.4)	220.5 (24.5)	214.3 (26.4)
Code substitution	57.0 (11.4)	59.8 (10.9)	56.9 (12.2)
Procedural reaction time	100.6 (15.6)	101.6 (10.6)	97.7 (17.6)
Matching to sample	37.0 (12.5)	38.2 (11.8)	37.3 (16.1)
Code substitution—delayed	52.1 (15.6)	54.8 (15.7)	51.6 (18.3)
Simple reaction time test 2	213.1 (32.7)	210.4 (38.9)	206.9 (30.5)
Neurocognition (Cogstate CCAT; n = 1407)			
Processing speed[c]	102.6 (6.0)	102.7 (5.6)	102.8 (4.9)
Attention[c]	105.8 (4.9)	105.8 (5.2)	106.5 (4.7)
Learning[c]	103.6 (9.5)	103.3 (10)	103.4 (14.1)
Working memory speed	102.7 (6.1)	103.4 (6.4)	103.5 (5.9)
Working memory accuracy	102.6 (8.2)	103.1 (8.9)	102.6 (7.9)

[a]Data are presented as mean (SD) unless otherwise indicated. ANAM, Automated Neuropsychological Assessment Metrics; BESS, Balance Error Scoring System; BSI-18, Brief Symptom Inventory–18; CARE, Concussion Assessment, Research, and Education; CCAT, Computerized Cognitive Assessment Tool; ImPACT, Immediate Post-concussion Assessment and Cognitive Testing; SAC, Standardized Assessment of Concussion; SCAT, Sport Concussion Assessment Tool.
[b]SCAT symptom severity and BSI-18 are reported as median and interquartile range.
[c]Outcomes are reported as composite scores.
[d]Outcomes are reported as raw scores.
[e]Outcomes are reported as throughput scores.

similar symptom severity profile to never concussed participants than to those who had experienced unreported concussions. Findings were nearly identical between symptoms and BSI-18. Immediate postconcussion diagnosis is critical and leads to a more efficient and safer return to play[2,3] while also serving as one of the most reliable predictors of concussion recovery.[26,31] Our results suggest that it is possible that undiagnosed, and therefore untreated, concussions lead to subtle lingering symptoms that persist beyond clinical concussion recovery. Athletes, military servicemembers, and clinicians treating these patient populations should be made aware of the risk for subtle lingering symptoms that may follow an undiagnosed concussion. Our findings may be related to previously reported higher symptom burdens in those with an undiagnosed concussion history.[46] Previous research has detailed increased symptom reporting in previously concussed athletes[10,14,15] but has not specifically explored the effect of self-reported previous concussion diagnosis status on subsequent symptom presentation. While our findings suggest a greater baseline symptom burden for those who reported ≥1 undiagnosed concussions, more research is needed to understand how undiagnosed concussions influence symptom presentation after subsequent concussion. It is possible that individuals who report a more thorough concussion history are also more thorough in reporting

TABLE 3
Multivariable Models Examining the Association of Previous Concussion Diagnosis Status and Concussion Baseline Assessment Outcomes: CARE Consortium, 2014-2018[a]

Outcome	All Previous Concussions Diagnosed vs No Concussion History	≥1 Previous Concussions Undiagnosed vs No Concussion History	≥1 Previous Concussions Undiagnosed vs All Previous Concussions Diagnosed
	Adjusted IRR (95% CI)		
Symptoms			
SCAT symptom severity (n = 29,696)	1.00 (0.88 to 1.14)	1.39 (1.20 to 1.61)[b]	1.38 (1.22 to 1.57)[b]
BSI-18 (n = 29,626)	0.94 (0.85 to 1.04)	1.31 (1.16 to 1.48)[b]	1.39 (1.28 to 1.51)[b]
	Adjusted Mean Difference (95% CI)		
Mental status (n = 28,848)			
SAC total score	0.09 (–0.001 to 0.19)	0.01 (–0.12 to 0.15)	–0.08 (–0.19 to 0.03)
Balance (n = 28,521)			
BESS total score	–0.11 (–0.51 to 0.30)	0.09 (–0.40 to 0.57)	0.20 (–0.21 to 0.60)
Neurocognition (ImPACT; n = 25,092)			
Verbal memory	0.04 (−0.48 to 0.55)	−1.23 (−2.17 to −0.30)	−1.27 (−1.91 to −0.63)[d]
Visual memory	0.19 (−0.70 to 1.09)	−0.53 (−1.78 to 0.71)	−0.72 (−1.34 to −0.11)[d]
Visual motor speed	0.04 (−0.36 to 0.43)	−0.51 (−0.90 to −0.12)[d]	−0.55 (−0.86 to −0.23)[d]
Reaction time[e]	−0.002 (−0.008 to 0.004)	0.003 (−0.002 to 0.009)	0.006 (−0.001 to 0.01)
Neurocognition (CNS Vital Signs; n = 1087)			
Verbal memory	−0.58 (−2.20 to 1.04)	−1.01 (−2.28 to 0.26)	−0.43 (−3.32 to 2.46)
Visual memory	−0.17 (−1.66 to 1.32)	−1.99 (−2.19 to −1.79)[c]	−1.82 (−3.12 to −0.52)[c]
Psychomotor speed	−0.22 (−2.45 to 2.01)	−5.11 (−11.35 to 1.12)	−4.89 (−13.34 to 3.57)
Reaction time[e]	−13.71 (−35.61 to 8.20)	15.17 (7.96 to 22.38)[d]	28.88 (14.17 to 43.59)[c]
Complex attention	−0.45 (−1.00 to 0.09)	0.32 (0.16 to 0.47)[d]	0.77 (0.09 to 1.45)[d]
Cognitive flexibility	0.79 (0.28 to 1.31)[d]	−0.01 (−2.39 to 2.36)	−0.81 (−3.65 to 2.04)
Processing speed	−0.99 (−3.98 to 2.00)	−4.11 (−7.06 to −1.15)[c]	−3.11 (−9.05 to 2.83)
Neurocognition (ANAM; n = 875)			
Simple reaction time test 1	5.33 (5.16 to 5.50)[d]	−1.63 (−7.24 to 3.98)	−6.96 (−12.73 to −1.19)[c]
Code substitution	1.27 (−0.19 to 2.74)	−1.00 (−2.45 to 0.44)	−2.28 (−5.19 to 0.64)
Procedural reaction time	0.51 (−0.17 to 1.20)	−3.11 (−4.66 to −1.57)[d]	−3.63 (−4.49 to −2.76)[c]
Matching to sample	−4.38 (−6.40 to −2.36)[c]	4.35 (−4.51 to −4.18)[c]	0.04 (−1.85 to 1.93)
Code substitution—delayed	0.18 (−0.37 to 0.72)	−2.56 (−2.81 to −2.30)[d]	−2.73 (−3.50 to −1.96)[d]
Simple reaction time test 2	10.33 (5.26 to 15.40)[c]	5.74 (−0.43 to 11.92)	−4.58 (−5.68 to −3.49)[d]
Neurocognition (Cogstate CCAT; n = 1407)			
Processing speed	−0.68 (−0.71 to −0.65)[d]	−0.85 (−0.88 to −0.82)[d]	−0.17 (−0.18 to −0.16)[d]
Attention	−0.37 (−0.40 to −0.35)[d]	0.22 (0.18 to 0.26)[d]	0.59 (0.57 to 0.61)[d]
Learning	1.68 (1.54 to 1.83)	2.56 (2.31 to 2.80)[c]	0.87 (0.77 to 0.98)[d]
Working memory speed	−0.27 (−0.40 to −0.13)[d]	−0.31 (−0.58 to −0.04)[d]	−0.04 (−0.18 to 0.09)
Working memory accuracy	0.83 (0.76 to 0.90)[d]	0.35 (0.19 to 0.52)[d]	−0.48 (−0.56 to −0.39)[d]

[a]All models controlled for sex, race, ethnicity, sport contact level, concussion count, and clustering by site. ANAM, Automated Neuropsychological Assessment Metrics; BESS, Balance Error Scoring System; BSI-18, Brief Symptom Inventory–18; CARE, Concussion Assessment, Research, and Education; CCAT, Computerized Cognitive Assessment Tool; ImPACT, Immediate Post-concussion Assessment and Cognitive Testing; IRR, incidence rate ratio; SAC, Standardized Assessment of Concussion; SCAT, Sport Concussion Assessment Tool.

[b]An IRR with 95% CI excluding 1.00 and at least a small association (ie, IRR, ≥1.10).

[c]A mean difference with 95% CI excluding 0.00 and at least a small effect size (ie, ≥0.20).

[d]Statistical significance (95% CI, excluding 1.00 or 0.00) but the effect size is marginal (ie, less than small).

[e]Higher value is worse.

symptoms during baseline concussion assessments, and this consideration should be noted when interpreting our findings.

Concussions are difficult to diagnose.[51] Despite advances, no single reliable biological marker is available.[41] In terms of both practical clinical use and the difficulty of obtaining noninvasive brain measures, the most sensitive indicator available to document ongoing brain function remains the symptom score.[50,52] The symptom score likely represents the closest measure we have to a global brain health indicator; however, the symptom score, while useful, is also noisy and subject to bias.[9,33,49] Concussed individuals can choose whether or not to report symptoms and then choose whether or not to be honest about the severity of those symptoms. It is important that health care providers continue to develop and implement effective measures aimed at improving concussion care seeking to enable timely diagnosis and treatment.

In some cases, the undiagnosed group performed worse than the other 2 groups on a given domain of one neurocognitive test, but the same or better on the corresponding domain of another neurocognitive test. For example, those who reported ≥1 concussions undiagnosed had slower reaction time than those who reported no concussion history and those with all concussions diagnosed on CNS Vital Signs, but faster simple reaction time and procedural reaction time on ANAM. The corresponding ImPACT reaction time domain elicited no between-group differences. Given these findings, it is difficult to discern how diagnosis status affects neurocognition, and overall results do not show a clear or consistent pattern of group differences.

There are several reasons why we may have observed significant group differences for some domains but not others. First, each neurocognitive testing platform has inherent differences, even if they report the same cognitive domain. For example, CNS Vital Signs calculates reaction time as the average reaction time during the Complex Reaction Time assessment (the participant strikes the spacebar when the color of the word and the name match, eg, "green" written in green color font) and the Stroop reaction time assessment (the participant strikes the spacebar when the color of the word and the name do not match, eg, "green" written in blue color font). ImPACT calculates reaction time as the average of the X's and O's assessment (pressing a given keyboard key when a specific color shape is presented), the Symbol Match assessment (the participant matches a keyboard number to a specific symbol), and the Color Match assessment (same as CNS Vital Signs Complex Reaction Time assessment). Thus, both neurocognitive testing platforms assess reaction time in a validated manner, but their definitions of reaction time are different. Second, many factors can influence performance on neurocognitive testing. Because of the longitudinal, multisite nature of the CARE Consortium, it is impossible to control for all factors. While we did account for some in our analyses, such as sex[8,13] and sport type,[25] we could not control for other potentially important factors, such as attention problems (eg, attention-deficit/hyperactivity disorder)[8] and age.[32] In addition to these differences, it is worth remembering that all measures—to include neuropsychological testing,[17] neuroimaging,[5] and symptom scores[50]—attempt to indirectly assess brain function or health and include significant variability or noise functions.

We did not observe any between-group differences regarding mental status (as measured by SAC) or balance (as measured by BESS). Both assessments were developed and recommended to be used in acute settings in which a concussion is suspected.[20] Given the nature of our study, it is not surprising that we observed no between-group differences using these measures, nor clear trends in the data. This strongly suggests that previous concussion diagnosis status does not affect SAC or BESS performance. It is possible that measures designed to assess chronic mental status and balance impairment could reveal differences related to concussion diagnosis status, but future studies will have to examine this possibility.

Our findings could affect baseline testing practices by identifying another factor that may affect performance (previous concussion diagnosis status). However, the bigger impact from this study is to add to the existing literature suggesting that subtle lingering concussion symptoms may result from injuries that go undiagnosed. This has important implications for preventive interventions. These findings provide compelling information about the cost of continued activity for athletes and military servicemembers. They add to a growing body of literature that makes the case that timely and honest concussion care seeking is ultimately helpful for athletic performance. Athletes who do not immediately report concussion symptoms and continue playing sport report more severe acute symptoms[2] and take longer to recover after concussion than those who immediately report concussion symtpoms.[3] Further, unreported and thus undiagnosed concussions result in an increased likelihood for recurrent postconcussion symptoms[47] and increase the chances of losing consciousness after subsequent concussion.[46] These findings are especially concerning given the fact that in military and civilian samples, <50% of individuals report concussions.[22,24,42,53,63] Clearly, prompt concussion diagnosis is critical. Our findings underscore the need for more targeted and effective interventions aimed at increasing timely concussion diagnosis. Although we examined young adult athletes and military cadets, incidences of undiagnosed concussion predated the baseline clinical outcome measures. Thus, intervention efforts must be broad and target youth athletes, the general public who may go on to become military servicemembers, stakeholders such as coaches and parents, and clinicians.

While these novel findings add to the existing literature, several limitations exist. We relied on participant self-report of concussion history and previous concussion diagnosis status. A standardized definition was provided, and participants were encouraged to answer truthfully. However, it is possible that some undiagnosed concussions were not reported or that some concussions that were reported as undiagnosed were not actually concussions. While we acknowledge this important limitation, the only way to collect undiagnosed concussion history is by participant self-report. It should be noted, however, that the findings reported here could be influenced by the self-reported nature of our data. To increase the overall statistical power and accommodate medical histories that were not designed for this analysis, we collapsed various diagnosis statuses within our group designations. Effectively monitoring the medical records of such a large participant cohort to extrapolate concussion history was beyond the scope of this study, and this limitation applies to all the broader CARE Consortium studies. Data collected across multiple sites may lead to differences based on the specific approach by which the data were collected, but we controlled for data collection site in our analyses, minimizing this limitation. Finally, we were limited by CARE Consortium methodology as to the assessments we could analyze. Other concussion baseline assessments have been recommended, such as tandem gait, visuospatial measures, and vestibular assessments, but were not utilized in this study.

CONCLUSION

Our data suggest that undiagnosed concussions are associated with some subsequently worse clinical indicators captured during a preseason evaluation, specifically symptom reporting. At baseline, military cadets and athletes who reported a history of at least 1 undiagnosed concussion had more severe symptoms, had worse BSI-18 composite scores, and performed worse on 6 neurocognitive outcomes compared with those with all previous concussions diagnosed and those with no concussion history. It should be noted that the neurocognitive findings were inconsistent, with other domains showing no difference between groups. This suggests that the negative consequences of concussion may be exacerbated when the injury is not diagnosed. These findings add to a growing body of literature suggesting that early concussion diagnosis, often facilitated by honest and timely care seeking by the injured individual, is critical to maximize recovery and increase positive health outcomes after concussion. Interventions are needed to increase the proportion of concussions that are diagnosed.

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REFERENCES

1. Allison PD. *Logistic Regression Using SAS: Theory and Application*. 2nd ed. SAS Institute; 2012.
2. Asken BM, Bauer RM, Guskiewicz KM, et al. Immediate removal from activity after sport-related concussion is associated with shorter clinical recovery and less severe symptoms in collegiate student-athletes. *Am J Sports Med*. 2018;46(6):1465-1474.
3. Asken BM, McCrea MA, Clugston JR, Snyder AR, Houck ZM, Bauer RM. ''Playing through it'': delayed reporting and removal from athletic activity after concussion predicts prolonged recovery. *J Athl Train*. 2016;51(4):329-335.
4. Barnhart M, Bay RC, Valovich McLeod TC. The influence of timing of reporting and clinic presentation on concussion recovery outcomes: a systematic review and meta-analysis. *Sports Med*. 2021;51(7):1491-1508.
5. Barth M, Breuer F, Koopmans PJ, Norris DG, Poser BA. Simultaneous multislice (SMS) imaging techniques. *Magn Reson Med*. 2016;75(1):63-81.
6. Broglio SP, Cantu RC, Gioia GA, et al. National Athletic Trainers' Association position statement: management of sport concussion. *J Athl Train*. 2014;49(2):245-265.

7. Broglio SP, McCrea M, McAllister T, et al. A national study on the effects of concussion in collegiate athletes and US military service academy members: the NCAA-DoD Concussion Assessment, Research and Education (CARE) Consortium structure and methods. *Sports Med*. 2017;47(7):1437-1451.
8. Brooks BL, Iverson GL, Atkins JE, Zafonte R, Berkner PD. Sex differences and self-reported attention problems during baseline concussion testing. *Appl Neuropsychol Child*. 2016;5(2):119-126.
9. Brooks BL, Kadoura B, Turley B, Crawford S, Mikrogianakis A, Barlow KM. Perception of recovery after pediatric mild traumatic brain injury is influenced by the ''good old days'' bias: tangible implications for clinical practice and outcomes research. *Arch Clin Neuropsychol*. 2014;29(2):186-193.
10. Brown DA, Grant G, Evans K, Leung FT, Hides JA. The association of concussion history and symptom presentation in combat sport athletes. *Phys Ther Sport*. 2021;48:101-108.
11. Clark JMR, Seewald PM, Wu K, Jak AJ, Twamley EW. Aspects of executive dysfunction and racial/ethnic minority status are associated with unemployment duration in veterans with a history of mild-to-moderate traumatic brain injury. *Arch Phys Med Rehabil*. 2020;101(8):1383-1388.
12. Collie A, Maruff P, Makdissi M, McCrory P, McStephen M, Darby D. CogSport: reliability cognitive tests used in and correlation with conventional postconcussion medical evaluations. *Clin J Sport Med*. 2003;13(1):28-32.
13. Combs PR, Ford CB, Campbell KR, Carneiro KA, Mihalik JP. Influence of self-reported fatigue and sex on baseline concussion assessment scores. *Orthop J Sports Med*. 2019;7(1):2325967118817515.
14. Cookinham B, Swank C. Concussion history and career status influence performance on baseline assessments in elite football players. *Arch Clin Neuropsychol*. 2020;35(3):257-264.
15. Cooper DB, Curtiss G, Armistead-Jehle P, et al. Neuropsychological performance and subjective symptom reporting in military service members with a history of multiple concussions: comparison with a single concussion, posttraumatic stress disorder, and orthopedic trauma. *J Head Trauma Rehabil*. 2018;33(2):81-90.
16. Copley M, Jimenez N, Kroshus E, Chrisman SPD. Disparities in use of subspecialty concussion care based on ethnicity. *J Racial Ethn Health Disparities*. 2020;7(3):571-576.
17. Czerniak LL, Liebel SW, Garcia GP, et al. Sensitivity and specificity of computer-based neurocognitive tests in sport-related concussion: findings from the NCAA-DoD CARE Consortium. *Sports Med*. 2021;51(2):351-365.
18. Defense Medical Surveillance System Theater Medical Data Store provided by the Armed Forces Health Surveillance Center. DoD Numbers for Traumatic Brain Injury: Worldwide Totals 2020-2021. Accessed August 10, 2022. https://health.mil/About-MHS/OASDHA/Defense-Health-Agency/Research-and-Development/Traumatic-Brain-Injury-Center-of-Excellence/DoD-TBI-Worldwide-Numbers
19. DiStefano LJ, Dann CL, Chang CJ, et al. The first decade of web-based sports injury surveillance: descriptive epidemiology of injuries in US high school girls' soccer (2005-2006 through 2013-2014) and National Collegiate Athletic Association Women's Soccer (2004-2005 through 2013-2014). *J Athl Train*. 2018;53(9):880-892.
20. Echemendia RJ, Meeuwisse W, McCrory P, et al. The Sport Concussion Assessment Tool 5th Edition (SCAT5): background and rationale. *Br J Sports Med*. 2017;51(11):848-850.
21. Elbin RJ, Sufrinko A, Schatz P, et al. Removal from play after concussion and recovery time. *Pediatrics*. 2016;138(3):e20160910. doi:10.1542/peds.2016-0910
22. Escolas SM, Luton M, Ferdosi H, Chavez BD, Engel SD. Traumatic brain injuries: unreported and untreated in an Army population. *Mil Med*. 2020;185(suppl 1):154-160.
23. Foster CA, D'Lauro C, Johnson BR. Pilots and athletes: different concerns, similar concussion non-disclosure. *PLoS One*. 2019;14(5): e0215030.
24. Fraas MR, Coughlan GF, Hart EC, McCarthy C. Concussion history and reporting rates in elite Irish rugby union players. *Phys Ther Sport*. 2014;15(3):136-142.
25. French J, Huber P, McShane J, Holland CL, Elbin RJ, Kontos AP. Influence of test environment, age, sex, and sport on baseline computerized neurocognitive test performance. *Am J Sports Med*. 2019;47(13):3263-3269.
26. Grubenhoff JA, Deakyne SJ, Brou L, Bajaj L, Comstock RD, Kirkwood MW. Acute concussion symptom severity and delayed symptom resolution. *Pediatrics*. 2014;134(1):54-62.
27. Gualtieri CT, Johnson LG. Reliability and validity of a computerized neurocognitive test battery, CNS Vital Signs. *Arch Clin Neuropsychol*. 2006;21(7):623-643.
28. Guskiewicz KM, Ross SE, Marshall SW. Postural stability and neuropsychological deficits after concussion in collegiate athletes. *J Athl Train*. 2001;36(3):263-273.
29. Hoge CW, McGurk D, Thomas JL, Cox AL, Engel CC, Castro CA. Mild traumatic brain injury in U.S. soldiers returning from Iraq. *N Engl J Med*. 2008;358(5):453-463.
30. Hopkins WG. Linear models and effect magnitudes for research, clinical and practical applications. *Sportscience*. 2010;14(1):49-58.
31. Houck Z, Asken B, Bauer R, Clugston J. Predictors of post-concussion symptom severity in a university-based concussion clinic. *Brain Inj*. 2019;33(4):480-489.
32. Houck Z, Asken B, Clugston J, Perlstein W, Bauer R. Socioeconomic status and race outperform concussion history and sport participation in predicting collegiate athlete baseline neurocognitive scores. *J Int Neuropsychol Soc*. 2018;24(1):1-10.
33. Iverson G, Lange R, Brooks B, Rennison VLA. ''Good old days'' bias following mild traumatic brain injury. *Clin Neuropsycholog*. 2010;24(1):17-37.
34. Johnson BR, McGinty GT, Jackson JC, et al. Return-to-learn: a post-concussion academic recovery program at the U.S. Air Force Academy. *Mil Med*. 2018;183(5-6):101-104.
35. Katz BP, Kudela M, Harezlak J, et al. Baseline performance of NCAA athletes on a concussion assessment battery: a report from the CARE Consortium. *Sports Med*. 2018;48(8):1971-1985.
36. Kontos AP, Jorgensen-Wagers K, Trbovich AM, et al. Association of time since injury to the first clinic visit with recovery following concussion. *JAMA Neurol*. 2020;77(4):435-440.
37. Kroshus E, Cameron KL, Coatsworth JD, et al. Improving concussion education: consensus from the NCAA-Department of Defense Mind Matters Research & Education Grand Challenge. *Br J Sports Med*. 2020;54(22):1314-1320.
38. Lovell MR, Iverson GL, Collins MW, et al. Measurement of symptoms following sports-related concussion: reliability and normative data for the post-concussion scale. *Appl Neuropsychol*. 2006;13(3):166-174.
39. Lynall RC, Mihalik JP, Pierpoint LA, et al. The first decade of web-based sports injury surveillance: descriptive epidemiology of injuries in US high school boys' ice hockey (2008-2009 through 2013-2014) and National Collegiate Athletic Association men's and women's ice hockey (2004-2005 through 2013-2014). *J Athl Train*. 2018;53(12):1129-1142.
40. McCrea M. Standardized mental status testing on the sideline after sport-related concussion. *J Athl Train*. 2001;36(3):274-279.
41. McCrea M, Broglio SP, McAllister TW, et al. Association of blood biomarkers with acute sport-related concussion in collegiate athletes: findings from the NCAA and Department of Defense CARE Consortium. *JAMA Netw Open*. 2020;3(1):e1919771.
42. McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K. Unreported concussion in high school football players: implications for prevention. *Clin J Sport Med*. 2004;14(1):13-17.
43. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5th International Conference on Concussion in Sport held in Berlin, October 2016. *Br J Sports Med*. 2017;51(11):838-847.
44. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med*. 2013;47(5):250-258.
45. Meachen SJ, Hanks RA, Millis SR, Rapport LJ. The reliability and validity of the Brief Symptom Inventory-18 in persons with traumatic brain injury. *Arch Phys Med Rehabil*. 2008;89(5):958-965.

46. Meehan WP III, Mannix RC, O'Brien MJ, Collins MW. The prevalence of undiagnosed concussions in athletes. *Clin J Sport Med*. 2013;23(5):339-342.
47. O'Brien MJ, Howell DR, Pepin MJ, Meehan WP III. Sport-related concussions: symptom recurrence after return to exercise. *Orthop J Sports Med*. 2017;5(10):2325967117732516.
48. Pierpoint LA, Collins C. Epidemiology of sport-related concussion. *Clin Sports Med*. 2021;40(1):1-18.
49. Piland SG, Ferrara MS, Macciocchi SN, Broglio SP, Gould TE. Investigation of baseline self-report concussion symptom scores. *J Athl Train*. 2010;45(3):273-278.
50. Piland SG, Motl RW, Ferrara MS, Peterson CL. Evidence for the factorial and construct validity of a self-report concussion symptoms scale. *J Athl Train*. 2003;38(2):104-112.
51. Putukian M. Clinical evaluation of the concussed athlete: a view from the sideline. *J Athl Train*. 2017;52(3):236-244.
52. Register-Mihalik JK, Guskiewicz KM, Mihalik JP, Schmidt JD, Kerr ZY, McCrea MA. Reliable change, sensitivity, and specificity of a multidimensional concussion assessment battery: implications for caution in clinical practice. *J Head Trauma Rehabil*. 2013;28(4):274-283.
53. Register-Mihalik JK, Kay MC, Kerr ZY, et al. Influence of concussion education exposure on concussion-related educational targets and self-reported concussion disclosure among first-year service academy cadets. *Mil Med*. 2020;185(3-4):e403-e409.
54. Rice SG; American Academy of Pediatrics Council on Sports Medicine and Fitness. Medical conditions affecting sports participation. *Pediatrics*. 2008;121(4):841-848.
55. Saadi A, Bannon S, Watson E, Vranceanu AM. Racial and ethnic disparities associated with traumatic brain injury across the continuum of care: a narrative review and directions for future research. *J Racial Ethn Health Disparities*. 2022;9(3):786-799.
56. Sawilowsky SS. New effect size rules of thumb. *J Mod Appl Stat Methods*. 2009;8(2):467-474.
57. Schmidt JD, Register-Mihalik JK, Mihalik JP, Kerr ZY, Guskiewicz KM. Identifying impairments after concussion: normative data versus individualized baselines. *Med Sci Sports Exerc*. 2012;44(9):1621-1628.
58. Schmidt JD, Weber ML, Suggs DW Jr, et al. Improving concussion reporting across National College Athletic Association divisions using a theory-based, data-driven, multimedia concussion education intervention. *J Neurotrauma*. 2020;37(4):593-599.
59. Terrio H, Brenner LA, Ivins BJ, et al. Traumatic brain injury screening: preliminary findings in a US Army Brigade Combat Team. *J Head Trauma Rehabil*. 2009;24(1):14-23.
60. Torres DM, Galetta KM, Phillips HW, et al. Sports-related concussion: anonymous survey of a collegiate cohort. *Neurol Clin Pract*. 2013;3(4):279-287.
61. Wallace J, Beidler E, Covassin T, Hibbler T, Schatz P. Understanding racial differences in computerized neurocognitive test performance and symptom-reporting to deliver culturally competent patient-centered care for sport-related concussion. *Appl Neuropsychol Adult*. Published online May 12, 2021. doi:10.1080/23279095.2021.1912047
62. Wallace J, Moran R, Beidler E, et al. Disparities on baseline performance using neurocognitive and oculomotor clinical measures of concussion. *Am J Sports Med*. 2020;48(11):2774-2782.
63. Williamson IJ, Goodman D. Converging evidence for the underreporting of concussions in youth ice hockey. *Br J Sports Med*. 2006;40(2):128-132.