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Collegiate Athletes With Diabetes: Baseline Medical Comorbidities and Preseason Concussion Testing Performance

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Context: People with diabetes mellitus (DM) are at increased risk for adverse health events and complications throughout their lifetime. Whether DM significantly affects collegiate athletes' concussion baseline testing performance remains unclear.

Objectives: To (1) describe the prevalence of DM and associated comorbidities and (2) compare concussion baseline testing performance between student-athletes with DM and student-athletes without DM (NoDM).

Design: Retrospective, cross-sectional study.

Setting: University.

Patients or Other Participants: Using the Concussion, Assessment, Research and Education (CARE) Consortium research database, we matched athletes with self-reported DM (N = 229) by institution, sex, age, sport, position, testing year, and concussion history to athletes with NoDM (N = 229; total sample mean age = 19.6 ± 1.4 years, women = 42%).

Main Outcome Measure(s): Descriptive statistics and χ^2 tests of independence with subsequent odds ratios were calculated. Independent-samples *t* tests compared baseline symptoms, neurocognitive testing, and balance performance between athletes with DM and athletes with NoDM. Effect sizes were determined for significant group differences.

Results: At baseline, athletes with DM had higher rates of self-reported pre-existing balance disorders, sleep disorders, seizure disorders, motion sickness, learning disorders, vision and hearing problems, psychiatric disorders, depression, bipolar disorder, nonmigraine headaches, and meningitis than athletes with NoDM (P values $< .05$). We found balance differences between groups ($P = .032$, Cohen $d = 0.17$) such that, on average, athletes with DM had 1 additional error on the Balance Error Scoring System (DM = 13.4 ± 6.5; NoDM = 12.1 ± 5.9). No other comparisons yielded significant results.

Conclusions: Although athletes with DM had high rates of self-reported balance disorders, sleep disorders, seizures, and meningitis, their baseline neurocognitive testing results were largely identical to those of athletes with NoDM. Our findings suggested that nonclinically meaningful differences were present in concussion baseline balance testing but no significant differences were noted in cognitive testing; however, the effect of DM on concussion recovery remains unknown.

Key Words: medical conditions, mild traumatic brain injuries, balance testing, neurocognitive testing

Key Points

- We observed no clinically meaningful differences in neurocognitive testing and balance performance between groups; athletes with diabetes performed similarly to athletes without diabetes.
- Athletes with diabetes had a disproportionally high rate of self-reported neurologic and mental health comorbidities compared with their nondiabetic counterparts.

The participation of individuals with diabetes mellitus (DM) in competitive sports has been made possible through advances in disease management strategies.[1] Although the exact number of college-aged athletes with DM is unknown, it is estimated to mirror the prevalence in the general population (4%).[2] Participating in team sports early in life has been linked to improved glycemic control, promotion of skeletal muscle oxidative capacity, and reduced macro- and

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microvascular complications and mortality in individuals with DM.[3] A diagnosis of DM does not keep athletes from competing in high-level sports, yet both the athlete and sports medicine professionals must be aware of the management challenges, including both hypoglycemia and hyperglycemia. A complex disorder, DM often coexists with other conditions, such as sleep disorders (up to 50%), asthma (10%–20%), and heart disease (up to 32%).[4–6] Professional medical organizations, such as the National Athletic Trainers' Association and the American Medical Society for Sports Medicine, have provided guidance on managing and caring for athletes with DM[1,7]; however, the effects of DM on concussion diagnosis and management are not well understood.

Considerable advances in recent decades have offered insight into the biological basis of diabetes and associated mental health disorders.[8–10] Importantly, people with DM are 2 to 3 times more likely to have depression than people without DM, which poses a potentially challenging interaction between having DM and being a varsity athlete.[10] Collegiate athletes face mental health challenges due to academic and athletic pressures, along with the social and emotional demands of college life.[11] Poorly managed mental health in athletes with DM could lead to inadequate management of the disease, which may result in negative health outcomes, including blindness, limb loss, and death, and carries significant societal and financial burdens.[8,12] Thus, a diagnosis of DM should serve as a "yellow flag" to prompt clinicians to evaluate an athlete's mental health and use established referral programs to ensure that the patient receives appropriate care.

Diabetes mellitus is also associated with changes in cognitive function across the lifespan, specifically mildly to moderately slower processing speed and decreased mental flexibility, most prominently in older adults.[13,14] Further, sleep disturbances and disorders are reported in up to 50% of people with DM.[4] The quality and quantity of sleep greatly affect cognition, and baseline neurocognitive testing should not be performed on sleep-deprived athletes for the sake of performance validity.[15–17] This can pose a challenge for athletes with DM who may have trouble obtaining adequate sleep. In current clinical practice, baseline testing results are often used for comparison in the event of a concussion.[18] However, an alternative approach is to compare postconcussion results with established normative data.[19] Therefore, understanding the performance of athletes with DM on baseline concussion assessments and how these groups may differ from group-based norms is crucial for proper concussion management.[19]

Collegiate athletes with DM are understudied, and having DM may present unique challenges for the treatment of athletes after concussion. Moreover, the incidence and effects of DM in collegiate athletes are largely unknown. Thus, the purpose of our study was 2-fold: (1) describe the prevalence of self-reported DM and neurologic and mental health comorbidities and (2) compare neurocognitive and concussion baseline testing performance between student-athletes with DM and student-athletes without DM (NoDM). We hypothesized that athletes reporting DM would display a higher rate of neurologic and mental health comorbidities and perform worse on cognitive and balance testing than athletes with NoDM.

METHODS

This study was part of the National Collegiate Athletic Association (NCAA) Department of Defense Concussion Assessment, Research and Education (CARE) Consortium, an investigation into the effects of concussions on collegiate student-athletes and US military service academy members from 2014 to 2020.[20] The University of Michigan institutional review board and the local institutional review board and Human Research Protection Office at each performance site reviewed and approved all study procedures. Individuals provided written informed consent before participation. Of the 60 720 baselines in the CARE dataset, 348 athletes (0.58%) self-reported having DM (60.9% men; age = 19.6 ± 1.4 years). Respondents were not required to specify whether they had type 1 DM (T1DM) or type 2 DM (T2DM). Athletes also self-reported a variety of comorbidities as part of a health history questionnaire. Data quality control revealed that some athletes who reported having DM also reported having a variety of additional comorbidities (ie, selected *yes* to all possible options, such as having Parkinson's disease, Alzheimer's disease, etc). These were deemed invalid responders and were subsequently excluded from all analyses (N = 119). This resulted in a final sample of 229 athletes with DM. Overall, although this select "yes to all" represented approximately 1/3 of the DM data set, it is important to note that this represented <0.2% of the CARE baseline data set.

The athletes with DM were then matched on demographic variables (sex, age, sport, position when applicable, testing year, and concussion history) with teammates with NoDM at the same institution. Approximately 78% (178/229) of the matches were performed by a blinded research team member who was not the first author and only had access to demographic information. The remaining 22% (51/229) of matches were performed by the primary author, who was blinded to information beyond demographics.

Baseline Concussion Testing

In addition to self-reported demographics and medical history, recruits completed a preparticipation balance assessment (Balance Error Scoring System [BESS]), symptom checklist (Sport Concussion Assessment Tool [SCAT3]), and cognitive assessments (Standardized Assessment of Concussion and Immediate Post-Concussion and Cognitive Testing). These assessments are discussed in detail elsewhere,[20] but, in brief, the BESS test consists of 3 stances: double-legged support, single-legged support (nondominant), and tandem-stance support (nondominant behind dominant). All 3 positions were performed on both a firm surface and a foam-padded surface while participants closed their eyes and placed their hands on their hips for 20 seconds. Total errors were scored per standard guidelines (range = 0–60), with a higher score indicating worse performance. The SCAT3 provided both total symptoms (range = 0–22) and symptom severity (range = 0–132) for 22 items. The Standardized Assessment of Concussion contains questions designed to assess an athlete's orientation, immediate memory, concentration, and delayed memory, with total scores ranging between 0 and 30. Finally, the Immediate Post-Concussion and Cognitive Testing computerized neurocognitive assessment provides clinicians with domain scores for verbal memory, visual memory, visuomotor speed, and

Table 1. Participant Demographics

	Diabetes Mellitus		No Diabetes Mellitus	
Demographic	No. (%)	Mean ± SD	No. (%)	Mean ± SD
Height, cm		169.5 ± 10.9		170.8 ± 12.3
Mass, kg		83.6 ± 21.9		82.4 ± 22.3
Age, y		19.6 ± 1.4		19.5 ± 1.4
Sex				
Female	96 (41.9)		96 (41.9)	
Male	133 (58.1)		133 (58.1)	
Sport				
Baseball	14 (6.1)		14 (6.1)	
Basketball	14 (6.1)		14 (6.1)	
Cheerleading	3 (1.3)		3 (1.3)	
Fencing	1 (0.4)		1 (0.4)	
Field hockey	2 (0.8)		2 (0.8)	
Football	69 (30.1)		69 (30.1)	
Golf	10 (4.4)		10 (4.4)	
Gymnastics	5 (2.1)		5 (2.1)	
Ice hockey	6 (2.6)		6 (2.6)	
Lacrosse	9 (3.9)		9 (3.9)	
Rowing	12 (5.2)		12 (5.2)	
Soccer	11 (4.8)		11 (4.8)	
Softball	12 (5.2)		12 (5.2)	
Swimming	11 (4.8)		11 (4.8)	
Tennis	8 (3.5)		8 (3.5)	
Track and field	28 (12.2)		28 (12.2)	
Volleyball	9 (3.9)		9 (3.9)	
Water polo	1 (0.4)		1 (0.4)	
Wrestling	4 (1.7)		4 (1.7)	

reaction time. Greater domain scores indicate better performance except for reaction time.

Statistical Analysis

To address our first aim, we calculated descriptive statistics (eg, frequencies) and χ^2 tests of independence between the DM and NoDM groups, followed by odds ratios for significant findings. Independent-samples *t* tests were conducted to determine differences in computerized neurocognitive testing, balance, symptom reports, and SCAT3 results between athletes with DM and those with NoDM. Cohen *d* effect sizes were computed for group differences.

RESULTS

Our final sample comprised 458 athletes (women = 192/458, 41.9%; age = 19.6 ± 1.4 years). Complete demographic information is presented in Table 1.

Prevalence of Comorbidities

Athletes in the DM group were more likely to self-report having a history of balance disorder ($P < .001$), sleep disorder ($P = .004$), seizure disorder ($P < .001$), motion sickness ($P = .004$), learning disorder ($P = .009$), vision ($P = .002$) and hearing ($P = .001$) problems, psychiatric disorders ($P = .002$), depression ($P = .005$), bipolar disorder ($P = .005$), nonmigraine headaches ($P = .013$), and meningitis ($P < .001$; Table 2). No differences were found between groups for the remaining self-reported health conditions.

Baseline Testing Performance

Group differences were evident in BESS results: athletes with DM committed 1.1 additional errors (ie, worse performance) than athletes with NoDM ($t_{2,1} = -1.85$, $P = .032$, Cohen $d = 0.18$). We observed no other group differences (Table 3). Visual representations of individual data points are provided in Figures 1 and 2.

DISCUSSION

Athletes with DM have been underrepresented in sport-related concussion research despite the potential implications for overall health and testing performance. Our primary finding was that athletes with self-reported DM had elevated rates of comorbidities (both physical and mental health) in baseline concussion testing performance. The BESS total score, although statistically significant, had a small effect size ($d = 0.17$) with limited clinical meaningfulness. These results suggested that health care providers should consider additional screening of athletes with diabetes at baseline to identify and treat possible comorbid physical and mental health conditions. However, these outcomes indicate that normative baseline data for balance and neurocognition[19,21] can be used for concussion management in athletes with DM as the baseline scores were similar between groups.

We noted a lower rate of college-aged athletes who self-reported having DM (0.73%) than that in the age-adjusted general population (DM = 4.0%), but we were not able to differentiate between athletes with T1DM and those with T2DM due to incomplete participant self-reporting.[2] Most often, T2DM occurs in adults ≥40 years of age; however, the incidence of T2DM in children is increasing, especially among American Indian, African American, and Hispanic and Latino populations. Meanwhile, T1DM is the rarer form of the disease, but athletic trainers working in middle schools, secondary schools, colleges, and many professional settings are more likely to encounter athletes with T1DM than athletes with T2DM.[7] Individuals with T1DM typically have had this diagnosis for a longer time before playing in the NCAA. As regular exercise is one of the main ways to prevent T2DM, it is likely that many of the athletes in our sample had T1DM. This is supported by the fact that the prevalence of DM in our large, multisite study of athletes more closely aligned with population norms specific to T1DM (T1DM = 0.55%).[22] Furthermore, athletes with DM had a disproportionally high risk of physical conditions, specifically balance disorders, sleep disorders, seizure disorders, and meningitis, versus collegiate athletes with NoDM.

We did not collect data specific to neuropathy or nerve disorders; however, an increased risk of balance disorders may be related to polyneuropathy, as the prevalence of diabetic polyneuropathy is 7% in youth with DM.[23] Although 27% of DM respondents self-reported having balance disorders, their balance performance showed minimal differences with a small effect size, indicating that either they may have been able to compensate at this stage in their life or they perceived balance difficulties in the absence of a formal diagnosis. Our finding translates to, on average, 1 more balance error committed by athletes with DM, which was not clinically meaningful (interrater minimal detectable change = 11.6).[24] Athletic health care providers working with middle-aged or older physically active individuals with DM should consider more comprehensive balance

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Table 2. Frequency of Comorbidities in Athletes With and Those Without Diabetes

Comorbidity	Diabetes Mellitus No. (%/229)	No Diabetes Mellitus No. (%/229)	χ^2 Value (Probability > χ^2)	Odds Ratio (95% CI)
Balance disorder[a]	63 (27.5)	24 (10.5)	36.48 (<.001)	3.10 (1.86, 5.14)
Sleep disorder[a]	53 (23.1)	25 (11.0)	12.37 (.004)	2.46 (1.47, 4.13)
Seizure disorder[a]	50 (21.8)	20 (8.8)	15.62 (<.001)	1.52 (0.87, 2.68)
Motion sickness[a]	20 (8.7)	6 (2.6)	8.41 (.004)	3.56 (1.40, 9.03)
Learning disorder[a]	23 (10.0)	9 (4.0)	6.94 (.009)	2.76 (1.24, 6.10)
Attention-deficit/hyperactivity disorder	39 (17.0)	26 (11.5)	3.12 (.077)	1.61 (0.94, 2.750)
Vision problems[a]	21 (9.2)	6 (2.6)	9.42 (.002)	3.75 (1.48, 9.48)
Hearing problems[a]	14 (6.1)	2 (0.9)	10.45 (.001)	7.75 (1.74, 34.52)
Psychiatric disorder[a]	58 (25.3)	27 (12.1)	13.88 (.002)	2.54 (1.54, 4.18)
Mood disorder	4 (1.7)	2 (0.9)	0.69 (.407)	2.08 (0.37, 11.12)
Anxiety disorder	9 (3.9)	5 (2.2)	1.20 (.274)	1.83 (0.60, 5.55)
Depression[a]	29 (12.7)	12 (5.3)	7.81 (.005)	2.62 (1.30, 5.28)
Bipolar disorder[a]	16 (6.9)	4 (1.8)	7.99 (.005)	4.23 (1.39, 12.84)
Personality disorder	3 (1.3)	1 (0.4)	1.06 (.304)	3.03 (0.31, 29.31)
Posttraumatic stress disorder	4 (1.7)	1 (0.4)	1.95 (.163)	4.05 (0.45, 36.55)
Somatic disorder	2 (0.8)	1 (0.4)	1.06 (.304)	2.01 (0.18, 22.31)
Nonmigraine headaches[a]	14 (6.1)	4 (1.8)	6.11 (.013)	3.66 (1.19, 11.30)
Migraine	24 (10.5)	14 (6.1)	2.95 (.086)	1.80 (0.91, 3.57)
Meningitis[a]	51 (22.3)	20 (8.6)	16.19 (<.001)	2.99 (1.72, 5.21)
Alcohol abuse	4 (1.7)	1 (0.4)	0.34 (.163)	4.05 (0.45, 36.55)
Drug abuse	2 (0.8)	1 (0.4)	0.34 (.56)	2.01 (0.18, 22.31)
Ménière disease	2 (0.9)	1 (0.4)	0.34 (.559)	NA
Moderate traumatic brain injury	0 (0.0)	0 (0.0)	NA	NA
Schizophrenia[a]	9 (3.9)	3 (1.3)	5.16 (.020)	3.08 (0.82, 11.53)
Vestibular disorder	1 (0.4)	0 (0.0)	NA	NA
Vertigo	8 (3.5)	3 (1.3)	2.41 (.120)	2.72 (0.71, 10.41)

Abbreviation: NA, not applicable.
[a] Indicates significance at the $P < .05$ level.

assessments, as these deficits may increase with age.[5] Furthermore, exploratory analyses conducted on the subset of athletes with DM who reported balance disorders revealed that they committed a similar number of BESS errors (mean = 12.8 ± 6.1) as those without a self-reported balance disorder (mean = 12.3 ± 5.9). The BESS has numerous documented limitations, including a practice effect from repeated administrations, test environmental influences, age, poor to mediocre reliability, and high minimal detectable change scores, which exceed the expected change acutely postconcussion.[24–26] The recently released SCAT6 incorporates single- and dual-task tandem gait, which likely has better psychometric values and has a higher area under the curve than the BESS in collegiate student-athletes.[27]

Additionally, DM has been associated with a 2-fold increased risk of bacterial meningitis,[28] which is consistent with our finding (odds ratio = 2.99), probably due to a remote history in childhood. Metabolic disorders such as DM can have a damaging effect on the central nervous system, leading to seizures in about 25% of patients,[29] which is in line with the higher prevalence of seizures (22%) in athletes with DM than in athletes with NoDM (odds ratio = 1.52).[23] The increased risk of physical conditions, including balance disorders, sleep disorders, seizure disorders, and meningitis in athletes with DM should be considered to ensure that the best care and support are provided to these individuals.

Approximately 13% and 6% of athletes with DM and those with NoDM, respectively, reported being diagnosed

Table 3. Diabetes Mellitus and Nondiabetic Comparisons for Concussion Baseline Test Performance

Score	Mean ± SD		P Value	Cohen d
	Diabetes Mellitus	No Diabetes Mellitus		
Balance Error Scoring System total (n = 458)	13.42 ± 6.49	12.31 ± 5.99	.032[b]	0.18
Sport Concussion Assessment Tool (n = 458)				
Total symptoms	2.35 ± 3.42	2.79 ± 3.92	.89	0.12
Symptom severity	4.07 ± 7.59	4.65 ± 7.56	.82	0.07
Standardized Assessment of Concussion total score (n = 458)	27.00 ± 2.16	27.08 ± 2.08	.66	0.03
Immediate Post-Concussion and Cognitive Testing (n = 318)				
Verbal memory	84.33 ± 10.57	85.80 ± 10.82	.78	0.13
Visual memory	74.18 ± 13.70	74.88 ± 12.60	.68	0.04
Visuomotor speed	39.30 ± 7.39	40.09 ± 7.61	.82	0.11
Reaction time[a]	0.61 ± 0.10	0.60 ± 0.09	.89	0.11

[a] Lower score indicates better performance.
[b] Indicates significance at the $P < .05$ level.

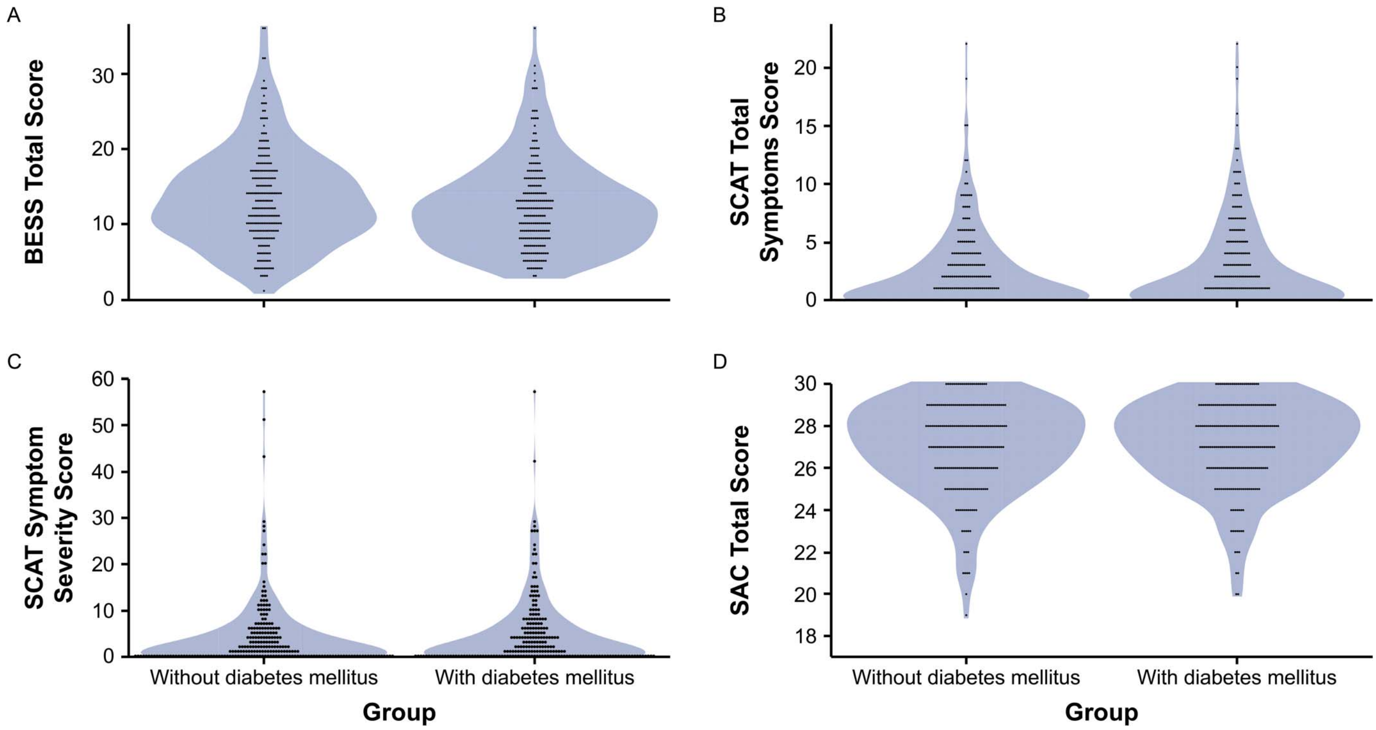

Figure 1. Violin plots of individual data points for all baseline concussion testing outcomes for athletes with and those without diabetes mellitus. (A) Balance Error Scoring System (BESS). (B) Sport Concussion Assessment Tool (SCAT) total symptoms. (C) SCAT symptom severity. (D) Standardized Assessment of Concussion (SAC) total score.

with depression, which was lower than the rate of depression in collegiate athletes as a whole (24%).[30] This outcome was surprising because DM is widely known to negatively affect mental health, and we expected that the rate of mental health concerns would be higher among athletes with DM.[9] Limited research is available on why depression rates might be lower in people with DM. Possible explanations include a sense of purpose and motivation, social support, active coping skills, and a positive mindset related to overcoming the challenges of managing DM.[31,32]

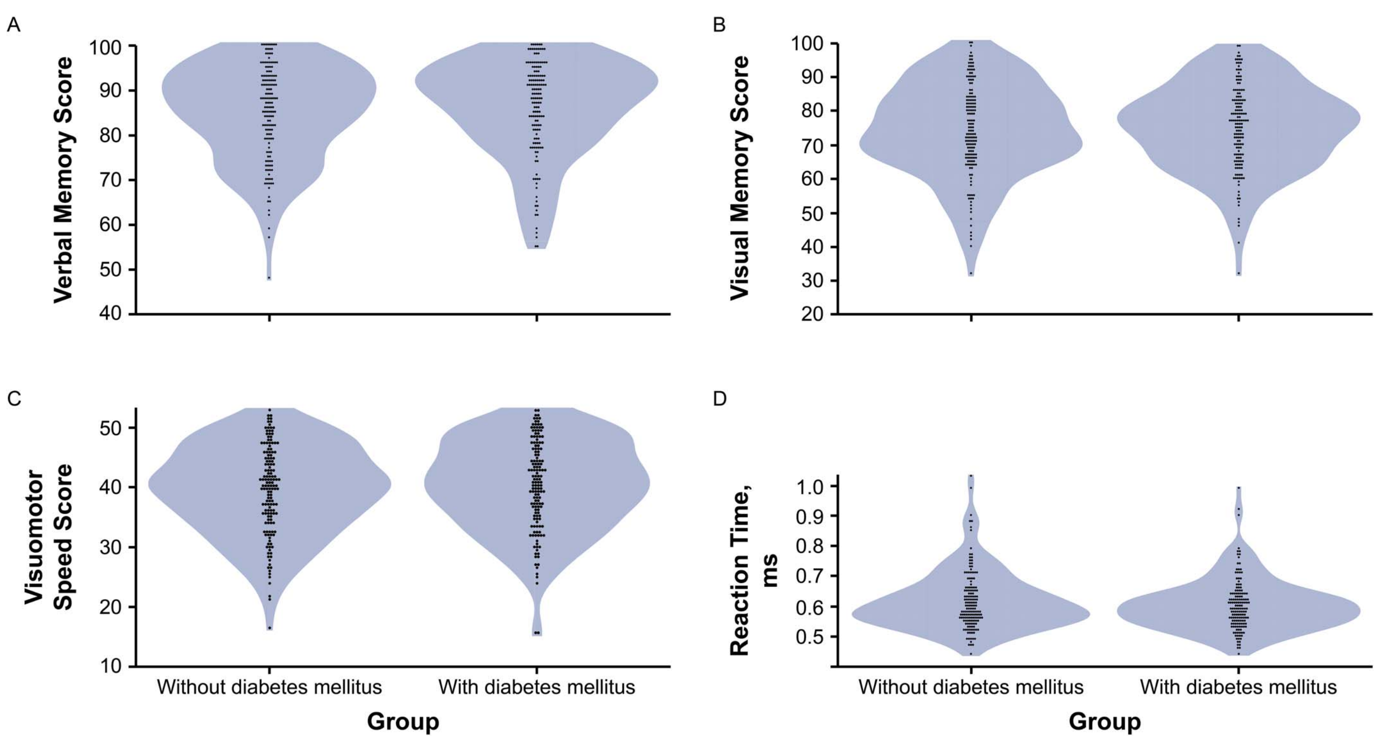

Figure 2. Violin plots of individual data points for computerized neurocognitive testing outcomes for athletes with and those without diabetes mellitus. (A) Verbal memory. (B) Visual memory. (C) Visuomotor speed. (D) Reaction time.

Yet we still observed a much higher rate of depression in athletes with DM than in those with NoDM. Further, all participants were highly active collegiate athletes who may have reaped the well-documented benefits of aerobic exercise in reducing depression.[33] Insulin resistance doubles the risk of developing a major depressive disorder,[34] which may explain the vastly different self-reported depression rates between the groups. It is important to note that despite being lower than expected, depression in athletes with DM was more than double that observed in athletes with NoDM (5.3%). The relationship between diabetes and depression is complex and can vary among individuals.

Finally, we did not demonstrate differences in symptom severity, total symptoms, or neurocognitive performance between the groups, and participant performance was similar to previously reported baseline values for college-aged athletes.[35] Although cognition decrements in individuals with DM are well documented in older adulthood, these differences did not seem to exist in a sample of young, healthy, physically active college students. The diabetes management of the participants was unknown, but poorly managed diabetes, even in young adults, results in poorer cognitive performance.[36–38] However, as all participants were collegiate athletes, a "healthy person" inclusion bias may have existed, whereby those athletes with poor diabetes management were not involved in intercollegiate athletics. The lack of expected differences in cognitive function in this study may have been due to the high level of physical activity and access to health care for diabetes management among the participants.[7] Individuals with better aerobic fitness have enhanced cognitive strategies, enabling them to respond more effectively and with better task performance. Thus, further research is needed to determine if physical fitness helps maintain cognitive ability throughout life; nonetheless, based on the current investigation, normative concussion baseline data do seem to apply to athletes with DM.

Limitations

All mental health conditions and medical histories were self-reported by the participants, which is an inherent limitation of questionnaire-based research. Additionally, the type of self-reported DM was not listed for 206 (90%) of the athletes; however, given the underlying pathophysiology of T2DM, it is unlikely that a significant proportion of T2DM would be present in collegiate athletes. The athletes were relatively young and thus unlikely to manifest advanced diabetic complications. Future authors should consider examining a slightly older cohort. Also, those with more DM comorbidities either may not have achieved this level of play or were not receiving the same level of care across institutions. Therefore, we cannot extrapolate our findings to other athletic populations. Large-scale, long-term, robust randomized controlled trials are required to determine if physical activity throughout life improves cognition in people with DM.

CONCLUSIONS

Recent improvements in DM management have made it possible for athletes with diabetes to compete at the collegiate, professional, and Olympic levels. We found an overall prevalence of 0.73%, which translates to 1 out of every 137 athletes having DM, slightly lower than in the general population. Although self-reported comorbidities were higher in athletes with DM, we did not identify differences in concussion baseline testing between athletes with DM and athletes with NoDM, except for differences in BESS testing. These results suggest that clinicians can use normative data for postconcussion management. Further investigation is needed to fully understand the potential effect of diabetes on concussion recovery. Finally, clinicians must be aware of the mental health challenges faced by all athletes, regardless of their diabetic status.

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