Brain Injury

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ibij20

Placing the keystone: the LIMBIC Military and Tactical Athlete Research Study

J. E. Resch, E Beidler, T. J. Bowman, T Kelshaw, M. J. Larson, T. A. Munce, J Oldham, S. R. Walton & D. X. Cifu

To cite this article: J. E. Resch, E Beidler, T. J. Bowman, T Kelshaw, M. J. Larson, T. A. Munce, J Oldham, S. R. Walton & D. X. Cifu (08 Feb 2024): Placing the keystone: the LIMBIC Military and Tactical Athlete Research Study, Brain Injury, DOI: 10.1080/02699052.2024.2304861

To link to this article: https://doi.org/10.1080/02699052.2024.2304861

BRAIN INJURY
https://doi.org/10.1080/02699052.2024.2304861

Taylor & Francis
Taylor & Francis Group

Placing the keystone: the LIMBIC Military and Tactical Athlete Research Study

J. E. Resch[a], E Beidler[b], T. J. Bowman[c], T Kelshaw[d], M. J. Larson[e], T. A. Munce[f], J Oldham[g], S. R. Walton[g], and D. X. Cifu[g]

[a]Department of Kinesiology, University of Virginia, Charlottesville, Virginia, USA; [b]Department of Athletic Training, Duquesne University, Pittsburgh, Pennsylvania, USA; [c]Department of Athletic Training, College of Health Sciences, University of Lynchburg, Lynchburg, Virginia, USA; [d]Department of Kinesiology, University of New Hampshire, Durham, New Hampshire, USA; [e]Department of Psychology and Neuroscience Center, Brigham Young University, Provo, Utah, USA; [f]Environmental Influences on Health and Disease Group, Sanford Research, Sioux Falls, South Dakota, USA; [g]Department of Physical Medicine and Rehabilitation, Virginia Commonwealth University School of Medicine, Richmond, Virginia, USA

ABSTRACT

Objective: The LIMBIC Military and Tactical Athletic Research Study (MATARS) framework was established to confirm and extend understanding of concussion with initial studies driven by clinical data collected between 2015 and 2020 in a collegiate sports setting. The LIMBIC MATARS framework will be leveraged to apply gold-standard and innovative research designs to advance the science of concussion. This manuscript provides the background, methodology, and initial demographic data associated with the LIMBIC MATARS.

Methods: Consensus-based common data elements were used to conduct a retrospective chart review, specific to collegiate athletes diagnosed with concussions between 2015 and 2020 at 11 universities.

Results: A final sample of 1,311 (47.8% female) concussions were diagnosed during the five-year study period from athletes participating in a variety of National Collegiate Athlete Association (NCAA) sports. The LIMBIC MATARS demographic data, align with the NCAA and other pioneering multi-site concussion-related studies in terms of biological sex, race and ethnicity, and sport participation.

Conclusion: This pragmatic, methodological approach was used to address several a priori hypotheses related to concussion, align with other multi-site studies of concussion, and establish a consortium for future investigations.

ARTICLE HISTORY
Received 2 March 2023
Revised 12 September 2023
Accepted 9 January 2024

KEYWORDS
Consortium; concussion; multi-site; collegiate athletes; National Collegiate Athletic Association

Introduction

A sport-related concussion (SRC) is defined as a mild traumatic brain injury (mTBI) induced by a direct blow to the head, neck, or body resulting in an impulsive force being transmitted to the brain that occurs in sport or exercise-related activities (1). Recently accepted diagnostic criteria for a concussion include a plausible mechanism of injury with one or more clinical signs and or two or more acute symptoms with remarkable clinical or laboratory findings (2). Notably, the role of computed tomography or magnetic resonance imaging has been deemphasized for the diagnosis of concussion by two multidisciplinary consensus groups in their conceptional and operational definitions (1,2).

During a five-year period, approximately 3,497 sport-related concussions were recorded at National Collegiate Athletic Association (NCAA) institutions, however, this estimate may only account for approximately 10% (3) to 30% (4) indicative of up to 37,784 during the period of time. In its updated concussion management policies and procedures (5), the NCAA mandated; 1) concussion education of stakeholders, 2) a pre-participation (baseline) multidimensional assessment, 3) the recognition and removal of athletes suspected of having concussions, 4) a post-concussion management plan, 5) return-to-learn and return-to-sport protocols, and 6) prevention strategies (6). In order to meet these standards, healthcare professionals across each of the 350 NCAA member institutions collect pre-injury (baseline), post-injury, and recovery data on collegiate athletes who participate in collision, contact, and non-contact sports as part of routine medical care (7). Baseline and post-injury data from NCAA athletes diagnosed with concussions each year in the United States are recorded within electronic medical records and other medical documentation (e.g., paper and other forms) and are often underutilized as the basis of empirical evidence (8).

The NCAA's concussion-related mandates have resulted in institution-specific datasets that consist of athletes' premorbid health information; a medical history related and unrelated to concussion, balance and neurocognitive test performance, and symptom data (7). Following a diagnosed concussion, data are often collected based on common clinical outcome variables. The clinical data are used to determine when athletes achieve recovery consistent with baseline performance, strategies to facilitate recovery (i.e., return-to-learn, subsymptom threshold exercise), the identification of persisting symptoms, the determination of return-to-sport (RTS), and health-related outcomes beyond RTS (9). The concussion-specific data are collected in each institution's unique framework consistent with their financial and human resources which adds ecological validity (i.e., generalizability) to our understanding of baseline and post-injury factors associated with concussion. These ecologically valid clinical data have the potential to help

CONTACT J. E. Resch Jer6x@virginia.edu Department of Kinesiology, University of Virginia, 550 Brandon Ave, Charlottesville, VA 22908, USA
Supplemental data for this article can be accessed online at https://doi.org/10.1080/02699052.2024.2304861.

clinicians and investigators identify clinically relevant and sustainable strategies to improve the healthcare of collegiate athletes at risk for concussion.

Despite the advances in methodology and the exponential increase in research over the last three decades, much remain unknown about concussions (9). In addition to the improved sophistication of clinical and laboratory-based measures of concussion, the emergence of multisite traumatic brain injury (TBI) networks have been developed to reduce the inter-site variability associated with non-standardized use of clinical measures, homogenous samples, and statistical approaches that have been used to reinforce and advance our understanding of clinical and physiological TBI-related outcomes (9–11).

Pioneering TBI-centric networks such as ENIGMA (12), LIMBIC-CENC (13), the NCAA-DOD CARE Consortium (14), and TRACK-TBI (15) have leveraged existing clinical and research infrastructures into multi-center, standardized protocols that enhance the understanding of TBI in collegiate athletes, tactical (i.e., military) athletes, and the general population alike. Collectively, these ground-breaking research consortia have demonstrated the feasibility of conducting coordinated large-scale, longitudinal studies related to TBI and more specifically concussion. To date, the collective findings of each of these clinical research programs have confirmed and extended our knowledge of baseline and post-injury considerations of varying severities of TBI, including concussion, and have contributed 400 + peer reviewed manuscripts. As an example, the Long-Term Impact of Military-Relevant Brain Injury Consortium (LIMBIC) Chronic Effects of Neurotrauma Consortium's (CENC) prospective longitudinal study initiated in 2013 is an ongoing, 17-center study examining the short- and long-term effects of single and repetitive, blast and non-blast, combat-related mTBIs in more than 2,800 service members and veterans through annual reevaluations (13). Using a single multi-modality, standardized assessment and follow-up approach applied to all participants, the prospective longitudinal study has identified a wide-range of baseline, injury, and post-injury factors associated with persisting symptoms and response to interventions following mTBI (13). Established in 2020, the 22-member LIMBIC Military and Tactical Athlete Research Study (LIMBIC MATARS) consortium serves as an extension of LIMBIC CENC.

LIMBIC Military and Tactical Athlete and Research Study (MATARS)

Background

A keystone is a remarkable, yet ordinary, wedge-shaped stone that stabilizes, strengthens, and unifies several stones of a preexisting structure (16). Using a standardized approach, the LIMBIC MATARS consortium is like a keystone in that the leadership and its site-specific principal investigators aim to stabilize, strengthen (i.e., reinforce best practices or identify and correct any weaknesses), and unify the concussion management and data collection protocols across its NCAA-member institutions. The overarching goals of LIMBIC MATARS are to 1) identify existing and novel biosignals that can enhance concussion identification and improve clinical and physiological recovery, 2) systematically investigate basic and advanced management approaches, and 3) lay the foundation for prospective longitudinal intervention studies to maintain and improve brain health of collegiate and tactical athletes.

An important first step in realizing each of the LIMBIC MATARS objectives was to leverage the existing clinical data at each member site. Using consensus-based common data elements, the LIMBIC MATARS consortium investigated concussion recovery based on demographic variables, premorbid diagnoses, the availability of resources, and management strategies. Our collective findings represent an ecologically valid 'snapshot' of concussion-management during a five-year period (2015–2020) at representative NCAA institutions; thus, these data provide valuable insight that may be leveraged by sports medicine professionals at peer institutions. The consortium framework (i.e., multisite collaborations, established data use agreements, and institutional review board approvals) established to collect data is also foundational for future descriptive and intervention-based studies to advance concussion research.

Core values

The LIMBIC MATARS consortium was established to confirm and extend our current understanding of concussion in collegiate athletes. More importantly, the LIMBIC MATARS leadership developed a framework to investigate gold-standard and innovative research approaches that may contribute to the growing body of concussion-related science. To achieve these goals, the LIMBIC-MATARS Co-PIs (JR, DC) established four core values for study methodology: 1) standardization, 2) innovation, 3) enhancing member sites, and 4) creating a dynamic research culture.

(1) For standardization, the LIMBIC MATARS leadership and site-PIs created a set of common data elements (CDEs) that were critical to the initial retrospective chart reviews of concussions from 2015 to 2020. The standardization of these CDEs was also identified as critically important to reduce the random and systematic error known to exist in clinical measures of concussion.
(2) Innovation reflects the desire to perform high-stakes studies that move the science and clinical management of concussion forward. For example, the use of wearable devices to record clinically informative biosignals and the application of targeted interventions using a randomized controlled trial design in future research efforts will further our understanding of concussion prevention, recognition, and rehabilitation.
(3) In terms of site enhancements, the creation and retrieval of uniform CDEs across all sites and the discussions this necessitated between the site-PIs and their respective sports medicine programs was an important first step in achieving this core value. Moving forward, the LIMBIC MATARS members will work collaboratively to establish a parsimonious methodological framework where sites may contribute and benefit from participation in our research consortium.
(4) The final core value is to establish a dynamic, high value national clinical research consortium. While prior key advancements in concussion research have occurred

largely based on single-site studies, the findings from single-site studies may not reflect that of the target population. On the other hand, the results of the multi-center LIMBIC MATARS reflect an ecologically valid 'snapshot' that can address several key questions aimed at extending current understanding of concussion in collegiate athletes and applying that knowledge to other populations (e.g., tactical, military, etc.) as well.

Approach

In addition to the significant effects on the daily lives of individuals around the world, the onset of the COVID-19 pandemic led to the restriction and restructuring of university research frameworks globally prompting the current research approach. Specific to collegiate athletics, university-based athletics departments throughout the United States halted practices and competitions during the spring of 2020 with resumption of modified activities several months later. These modified activities included frequent COVID-19 testing, distancing efforts, postponement or cancellation of athletic practices or competitions within hours of a known positive test, quarantine procedures for those within hours of a known or suspected diagnosis, cardiopulmonary screening post-recovery, the continual modification of each athletes' academic curriculum, and systemic adjustments to each institutions' academic and research enterprises (17). These institutional adjustments greatly impacted data collection across the United States, including prospective human subject research studies. Therefore, the LIMBIC MATARS leadership decided to perform a multi-site, retrospective chart review leveraging data that had been collected at each participating site prior to the onset of the pandemic.

The LIMBIC MATARS Co-PIs and all site PIs convened to create consensus-based CDEs specific to data collected from collegiate athletes who were diagnosed with concussion during the five-year study period and specific to each participating institution's athletic department sports medicine program. It is important to note, that despite the existence of the National Institute of Neurological Disorders and Stroke CDEs (18), many clinical sites have not adopted them for clinical purposes as with our current institution partners. More importantly, the LIMIC MATARS CDEs were selected to address *a priori* hypotheses. Each data collection site achieved institutional review board approval and completed confidentiality disclosure and data use agreements with one Co-PI's (JR) university. The site-PIs then retrieved the CDEs for each injured athlete, de-identified each case, and sent the worksheet back to the Co-PI (JR). All site data was then coded by site, to ensure anonymity, aggregated, and redistributed to all stakeholders (Figure 1). The Co-PI (JR) did not remove (i.e., clean) any data from the data set prior to dissemination to each member site. The decision to not remove data prior to distributing to partner sites was made to minimize the risk of excluding data necessary to address each investigator's hypotheses for the formation of each manuscript. For example, for some hypotheses, a history of headache or migraine served as inclusion criteria and those without these data were excluded from analyses, however, the same CDEs may be less critical for a different hypothesis or research question and would not warrant those cases being excluded, therefore, the entire set of submitted concussion cases remained in the original data set. Missing data served another important, yet manifest function, which was to provide the state of what medical records were or were not captured at each member site. Though

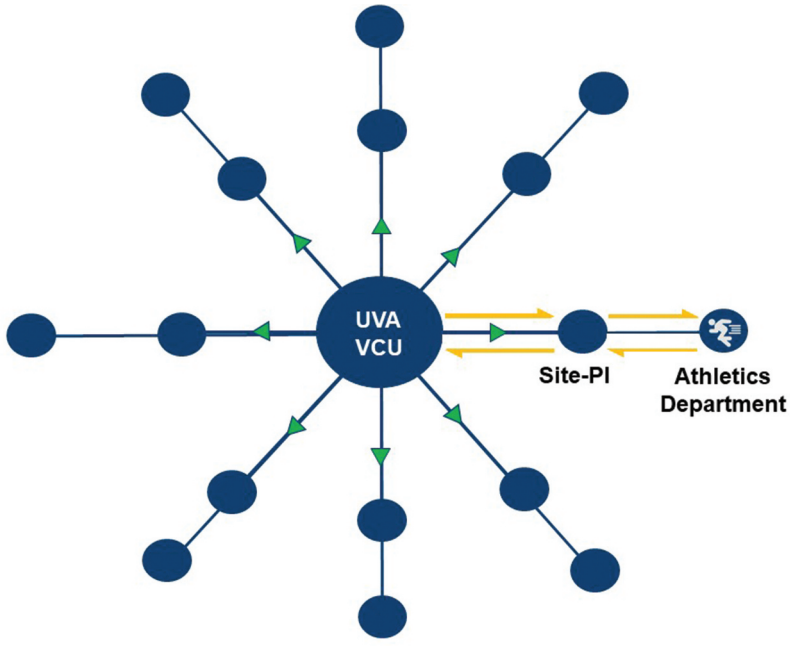

Figure 1. A depiction of the hub-and-spokes model of data collection that occurred between the Co-PIs (JR, DC) and each LIMBIC MATARS site PI. Upon establishment of IRB approval as well as confidentiality disclosure and data use agreements, common data elements were distributed to each member site. Site investigators created a de-identified data set that was sent back to the Co-PIs. The Co-PIs then sent, in aggregate, the 11-site data set to all LIMBIC MATARS investigators for cleaning and analysis.

unintended, the observation led to enhanced communication between each site-PI and their medical teams to better record certain CDEs.

Data management

Each LIMBIC MATARS member site was charged with collecting CDEs. Though using a consensus approach is empirically sound, it is imperfect. Coding operationalization of many CDEs was dichotomous, albeit based on theoretically sound definitions. For example, biological sex was coded as male or female and race was categorized based on the National Institutes of Health guidelines (19). However, other CDEs had less clear definitions that required in-depth discussions amongst the LIMBIC MATARS partners. For example, the categorization of 'level of exposure to an athletic trainer' was developed to address the inherent variability of athletic trainer coverage across member sites and divisions of play.

Though some definitions used for the LIMBIC MATARS CDEs were anecdotally or theoretically derived, these definitions may collectively better reflect the state of medical records kept within NCAA athletic departments across the United States (4). Additionally, to account for how data were entered at each respective site, some CDEs may reflect a more general idea of an athlete's medical history. One example of this is the self-reported diagnosis of anxiety or depression. This dichotomous variable was collected via the medical records for each athlete with a diagnosed concussion. While some member institutions retrieved this information from electronic medical records other sites may have retrieved this information from paper files or the medical history domain from a computerized cognitive assessment. Despite the variability between sites, the information is still viewed as self-reported history of premorbid anxiety or depression. The management of missing data was also addressed using a consensus-based approach. Of our 22-member sites, 11 institutions contributed data to our master data set (Table 1). Though our final data set yielded 1,311 documented concussions, several cases had missing CDEs which resulted in the included 1,044 cases.

Participant demographics

The following analyses describe data retrieved from the LIMBIC MATARS data collection sites during the 2015–2020 sport seasons. It is important to note that these data reflect the total number of concussion cases reported in terms of general demographics. As is true with other consortium-based studies, samples used for LIMBIC MATARS-related manuscripts will be highly variable based on specific inclusion and exclusion criteria related to each hypothesis addressed.

NCAA sports medicine programs

The final LIMBIC MATARS dataset consisted of data from 11 institutions sponsoring NCAA athletics. For participating LIMBIC MATARS sites that did not contribute data, the reasons included site-specific institutional review board differences, inadequate support staff (i.e., research coordinators, athletic trainers, or students), and not being an NCAA institution (e.g., healthcare systems). The LIMBIC MATARS investigators who did or did not contribute site-specific data worked collaboratively on the manuscripts to support the goals of this important first step and contribution of this emerging consortium. The multi-site author groups worked together to minimize the potential for site-specific bias (e.g., bias associated with investigators from sites who did or did not submit data). The lack of support staff for specific sites to assist with data entry will be addressed with external funding for future research studies moving forward. The descriptive data for contributing member sites may be found in Table 1.

NCAA member sites that contributed data consisted of four Power 5 Division I institutions, four Non-Power 5 Division institutions, two Division II institutions, and one Division III institution. An interesting observation was that non-Power 5 institutions, on median, had a third of the number of athletic trainers as compared to Power-5 institutions. Additionally, our sole Division III institution had more certified athletic trainers than either Division II institution. Our observation is interesting as the Division III institutions had 20% fewer athletes compared to the Division II institution. The variability associated with the number of athletic trainers at each division of collegiate sport may have implications for the recognition and removal from play following a concussion (20–22), the selection and use of clinical measures of concussion prior to and following injury (23), and management strategies as an athlete returns-to-sport following their injury (24,25).

Collectively, though 1,311 concussions were retrieved, a final sample of 1,044 (79.6%) concussion cases were retained across the 11 member sites after applying our our exclusion criteria and removing erroneous or missing data (Figure 2). Over the five-year study period, this resulted in an average of 94 concussions reported at each site per year. The total number of collegiate athletes who participated in NCAA sponsored sports at each contributing site over the five-year period was 26,585 (48.7% female). The total percent of athletes diagnosed with a concussion, prior to excluding cases, was 4.9% (1,311/26,585) which is comparable to the 5.8% (2,256/38,888) of athletes diagnosed with a concussion during a four-year period reported by the NCAA-DoD CARE Consortium (26).

Table 1. Descriptive data of LIMBIC MATARS sites who contributed data to related manuscripts.

NCAA Division	N	Athletic Trainers Median (Range)	Number of Athletes (% female)	Number of Concussions
I (Power 5)	4	21 (12–23)	12,502 (50.7%)	601
I (Non-Power 5)	4	8 (7–12)	8,254 (47.8%)	491
II	2	3 (2–5)	3,255 (43.8%)	119
III	1	6	2,574 (48.9%)	100

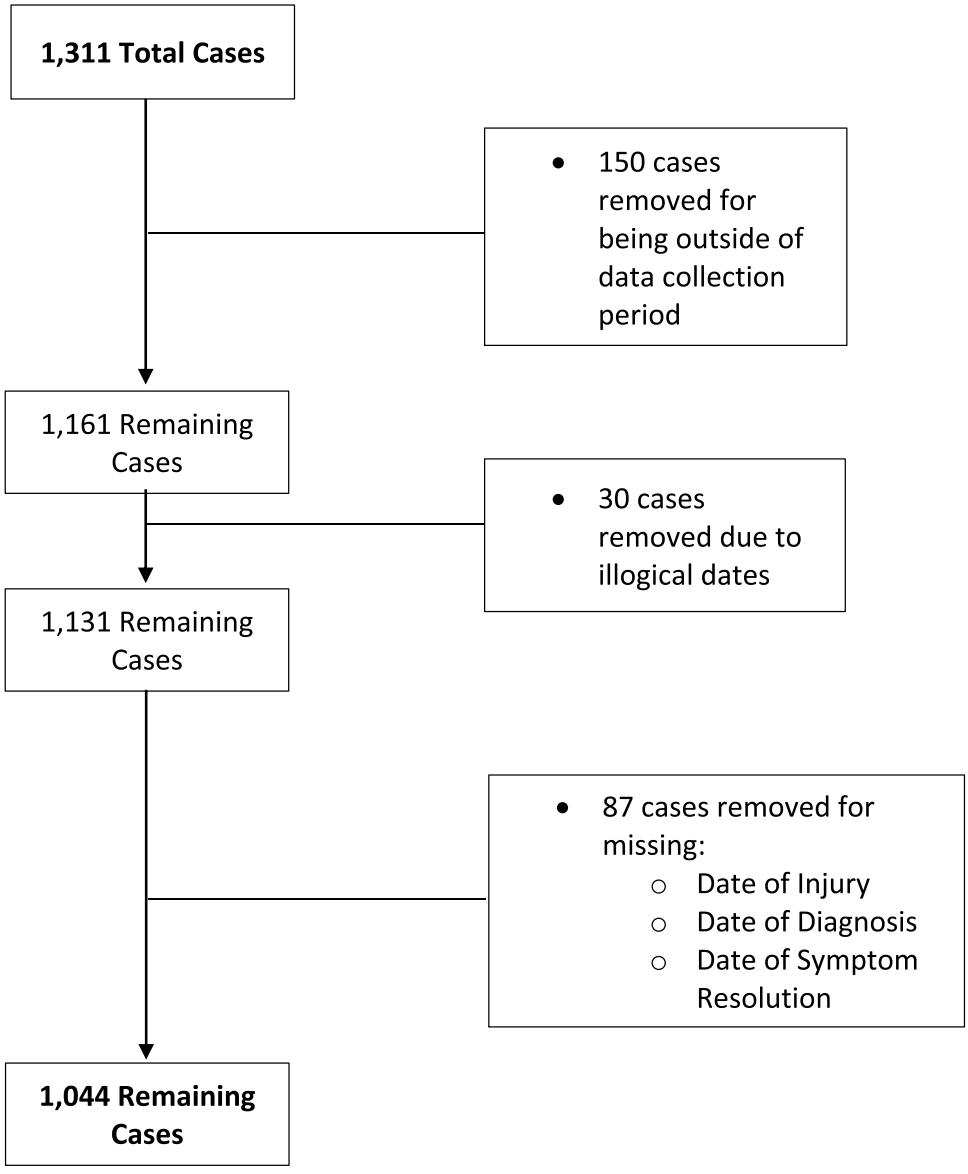

Figure 2. A consort diagram depicting the exclusion of data from our initial LIMBIC MATARS data set. No further data cleaning occurred prior to distribution of this data set as cleaning additional variables may have unnecessarily reduced the sample size for each related manuscript.

Preliminary site specific and demographic data

Patterns of reported diagnosed concussions by sport were similar to those reported in the literature (Figure 3) (8,27). The majority of recorded concussions occurred in American football (36.3%) with the fewest concussions occurring in women's rifle and men's golf (0.10%, each). A limitation of the current data set is that certain sports (e.g., equestrian and sailing) were only represented by a few institutions, thus, our findings may not be generalizable for less represented sports. Also, similar to previously reported data, we observed that female collegiate athletes had an equal, if not higher, frequency of concussions as compared to male athletes in the same or similar sports (17).

Specific to biological sex (Figure 4a-c), the highest number of concussion among females were recorded for women's soccer (19.2% [86/447]) and the fewest were observed in women's cross-country (0.20% [1/447]) and rifling (0.20% [1/447]). For males, the highest number of concussions were recorded in American football (63.4% [376/593]) and the least were reported for cross country (0.20% [1/593]) and golf (0.20% [1/593]) which are consistent with published data (27,28).

In terms of race or ethnicity, our data align with published data by the NCAA (29). The majority of concussion cases in this study identified as White or Caucasian (67.7%[536/1044)]) athletes followed by Black or African American (17.4% [182/1044]), Hispanic (1.3% [10/1044]), Native Hawaiian or Other Pacific Islander (1.10% [9/1044]), Asian (0.60%[5/1044]), and American Indian or Alaska Native (0.20%[2/1044]) athletes. Approximately 4.6% (48/1044) of documented concussions occurred to athletes that self-identified as 'Other.' The percent of self-endorsed categories for reach or ethnicity in the LIMBIC MATARS data set are in alignment with the NCAA (29).

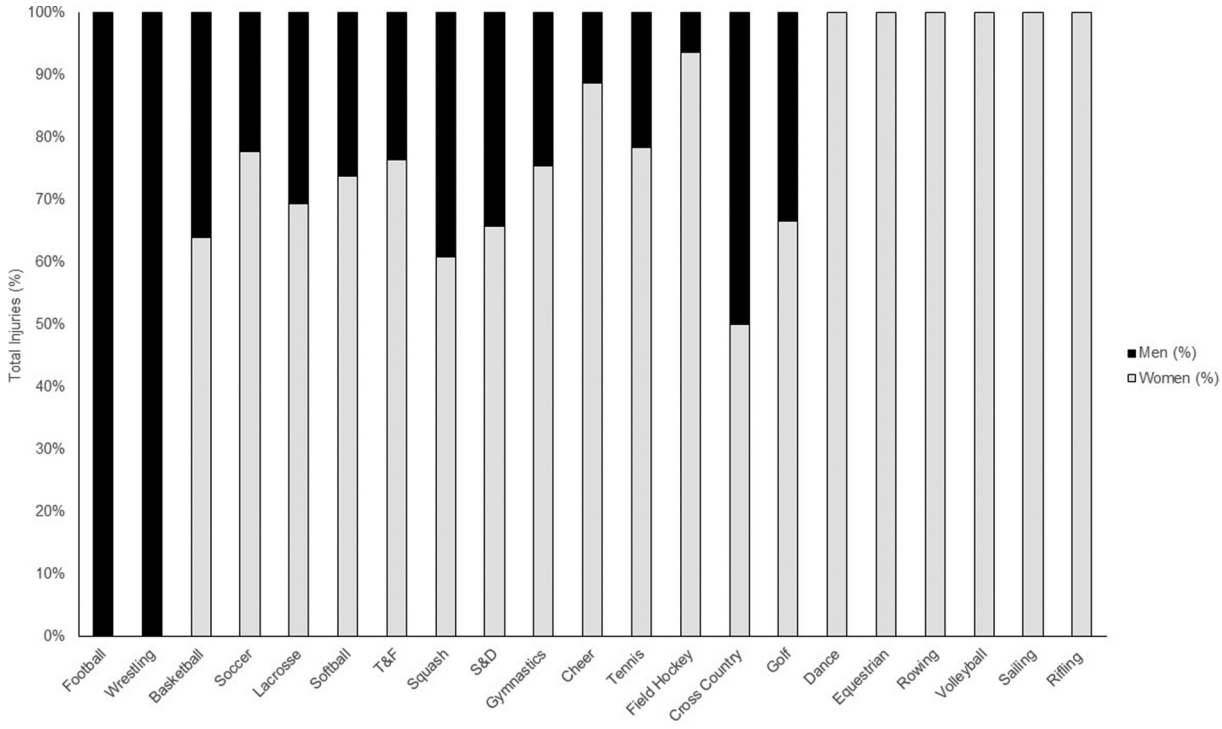

Figure 3. A comparison of the percent of concussions within the LIMBIC MATARS data set (n=1044) by men's and women's collegiate sports. T&F = Track and Field; S&D =Swimming and Diving.

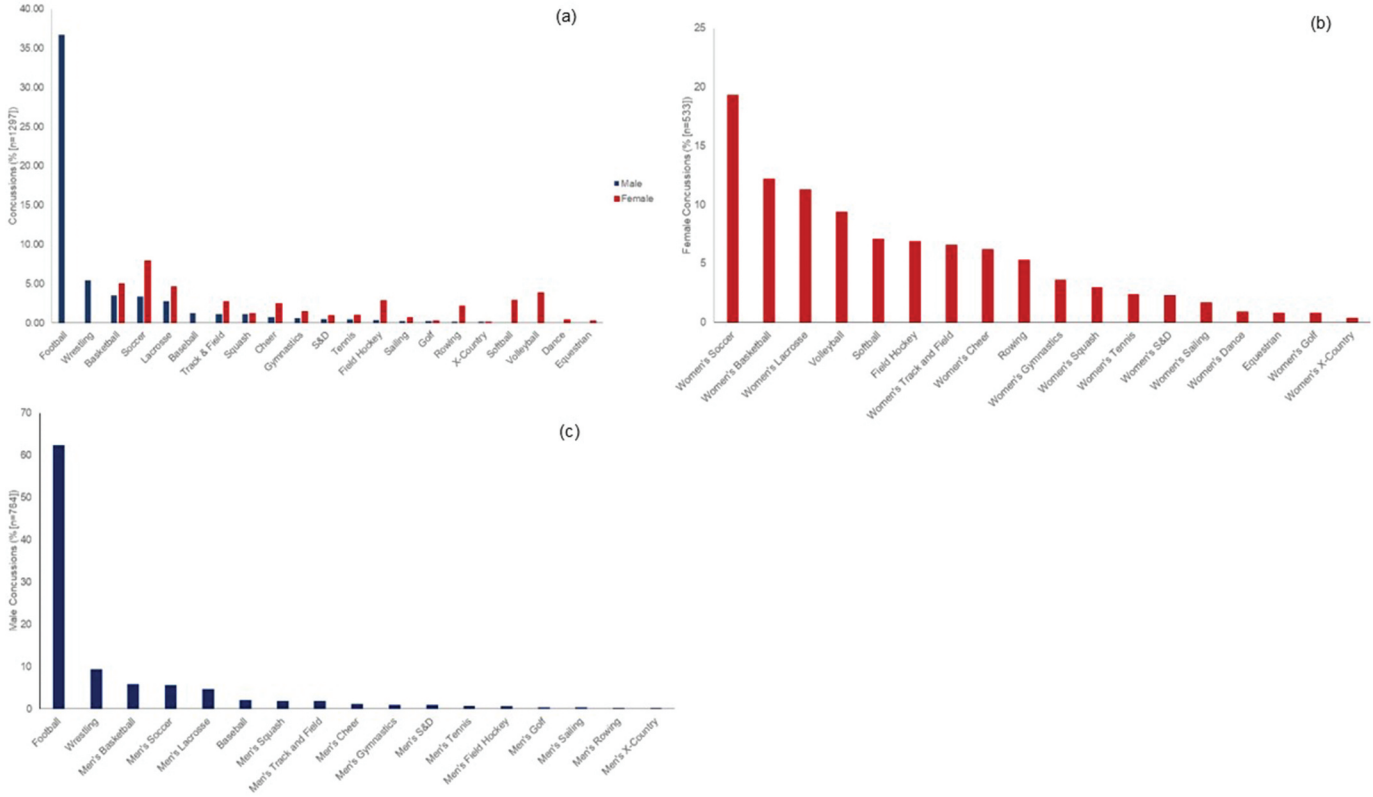

Figure 4. Concussion cases (%) by (a) sport and biological sex as well as for (b) women's and (c) men's sports.

Conclusion

The LIMBIC MATARS is a pragmatic framework that reflects an ecologically valid picture of concussion management of collegiate athletes at 11 NCAA institutions. The data reflected in this paper and other manuscripts derived from this research effort reflect clinical practice related to collegiate athletes with concussion during a recent five-year period. The clinical translation of our findings will assist clinicians by reinforcing their current clinical practice and by highlighting potential areas for improvement. For researchers, our pragmatic research model represents an alternative approach to data collection when prospective studies may be limited, a framework for the development of prospective multi-site consortium, and collective findings that will assist with hypothesis generation for future research. The findings of our initial study will be the 'keystone' in the establishment of the LIMBIC MATARS consortium to achieve its core values and confirm and extend our understanding of concussion in collegiate and tactical athletes.

Acknowledgments

The authorship would like to acknowledge the contributing LIMBIC MATARS site investigators: Michelle Kirk, M.D. and David Gable, ATC, (Texas Christian University), Brett Mortensen, Ph.D., Michael J. Larson, Ph.D., (Brigham Young University), Erica Beidler, Ph.D. (Duquesne University), James Day, Ed.D. (Augustana University), Thayne Munce, Ph.D. and Allison Peplowski (University of South Dakota), Trish Kelshaw, Ph.D., (University of New Hampshire), Kristin Wilmoth, Ph.D., Nyaz Didehbani, Ph.D., and C. Munro Cullum, Ph.D., (The University of Texas Southwestern Medical Center), Meredith Decker, Ph.D., (The University of Texas at Arlington), Tom Campbell, Ph.D., ATC (Old Dominion University), Monique Pappadis, Ph.D. (The University of Texas Medical Branch), Sean Ahonen, ATC (Virginia Union University), Verle Valentine, M.D. (Sanford Health), Kate Higgins, Psy.D. and Heather Bouchard, M.A. (University of Nebraska), Jessica Wallace, Ph.D. (University of Alabama), Jessica Gill, Ph.D. (Johns Hopkins University), Catherine Donahue, M.Ed., Daniel Rosenblum, M.Ed., Donna Broshek, Ph.D. and Rachel Smetana, Ph.D. (University of Virginia), Thomas G. Bowman, Ph.D., ATC, Caroline Wesley Siler, MS, ATC, and Tenesha Helm, MSAT, ATC (University of Lynchburg), Samuel Walton, Ph.D., and Jessie Oldham, Ph.D. (Virginia Commonwealth University) as well as the NCAA collegiate athletes who contributed to this dataset.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

XXXXX: External funding from the Medical Technology Enterprise Consortium, the Defense Advanced Research Projects Agency, BioCore Inc. to examine the effects of sport and military-related mild traumatic brain injuries or work-related exposures. XXXXX has also received honoraria as a consultant for the Virginia Concussion Initiative related to high school related to sport related concussion. XXXXX. None declared. XXXXX. None declared. XXXXX: None declared. XXXXX: None declared. XXXXX: None declared. XXXXX: None declared. XXXXX: Receipt of honorarium and travel costs from the National Athletic Trainers' Association 2022 Clinical Symposia. XXXXX: None declared.

ORCID

T. J. Bowman http://orcid.org/0000-0002-0034-2946
M. J. Larson http://orcid.org/0000-0002-8199-8065

References

1. Patricios JS, Schneider KJ, Dvorak J, Ahmed OH, Blauwet C, Cantu RC, Davis GA, Echemendia RJ, Makdissi M, McNamee M, et al. Consensus statement on concussion in sport: the 6th International Conference on Concussion in Sport–Amsterdam, October 2022. Br J Sports Med. 2023;57(11):695–711. doi:10.1136/bjsports-2023-106898.
2. Silverberg ND, Iverson GL, ACRM Brain Injury Special Interest Group Mild TBI Task Force members, Cogan A, Dams-O-Connor K, Delmonico R, Graf MJP, Iaccarino MA, Kajankova M, Kamins J, McCulloch KL. The American Congress of Rehabilitation Medicine Diagnostic Criteria for Mild Traumatic Brain Injury. Arch Phys Med Rehabil. 2023;104(8):1343–55. doi:10.1016/j.apmr.2023.03.036.
3. Arbogast KB, Curry AE, Pfeiffer MR, Zonfrillo MR, Haarbauer-Krupa J, Breiding MJ, Coronado VG, Master CL. Point of health care entry for youth with concussion within a large pediatric care network. JAMA Pediatr. 2016;170(7):e160294. doi:10.1001/jamapediatrics.2016.0294.
4. Kerr ZY, Mihalik JP, Guskiewicz KM, Rosamond WD, Evenson KR, Marshall SW. Agreement between athlete-recalled and clinically documented concussion histories in former collegiate athletes. Am J Sports Med. 2015;43(3):606–13. doi:10.1177/0363546514562180.
5. National Collegiate Athletics Association Sport Science Institute. Concussion safety protocol checklist. 2017.
6. Sport Concussion Institute NCAA. Concussion Safety Protocol Checklist. National Collegiate Athletics Association Sport Science Institute; 2022 [accessed 2022 Dec 2]. p. 1–10. https://ncaaorg.s3.amazonaws.com/ssi/concussion/SSI_ConcussionSafetyProtocolChecklist.pdf.
7. NCAA.org. [accessed 2023 Feb 20]. Concussion safety protocol management. https://www.ncaa.org/sports/2016/7/20/concussion-safety-protocol-management.aspx.
8. Epidemiology of Concussions in National Collegiate Athletic Association (NCAA) Sports; 2014/15-2018/19. [accessed 2022 Dec 2]. https://journals.sagepub.com/doi/epub/10.1177/03635465211060340.
9. McCrory P, Meeuwisse W, Dvorak J, Aubry M, Bailes J, Broglio S, Cantu RC, Cassidy D, Echemendia RJ, Castellani RJ, Davis GA. Consensus statement on concussion in sport-the 5th international conference on concussion in sport held in Berlin. Br J Sports Med. 2017;51(11) 838–847.
10. Kamins J, Bigler E, Covassin T, Henry L, Kemp S, Leddy JJ, Mayer A, McCrea M, Prins M, Schneider KJ, et al. What is the physiological time to recovery after concussion? A systematic review. Br J Sports Med. 2017;51(12):935–40. doi:10.1136/bjsports-2016-097464.
11. McCrea M, Broshek DK, Barth JT. Sports concussion assessment and management: future research directions. Brain Inj. 2015;29(2):276–82. doi:10.3109/02699052.2014.965216.
12. Dennis EL, Baron D, Bartnik-Olson B, Caeyenberghs K, Esopenko C, Hillary FG, Kenney K, Koerte IK, Lin AP, Mayer AR, et al. ENIGMA brain injury: framework, challenges, and opportunities. Human Brain Mapping. 2020;43(1):149–66. doi:10.1002/hbm.25046.
13. Cifu DX. Clinical research findings from the long-term impact of military-relevant brain injury consortium-chronic effects of Neurotrauma consortium (LIMBIC-CENC) 2013-2021. Brain Inj. 2022;36(5):587–97. doi:10.1080/02699052.2022.2033843.
14. Broglio SP, McCrea M, McAllister T, Harezlak J, Katz B, Hack D, Hainline B. 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):1437–51. doi:10.1007/s40279-017-0707-1.
15. Dams-O'Connor K, Spielman L, Singh A, Gordon WA, Lingsma HF, Maas AIR, Manley GT, Mukherjee P,

Okonkwo DO, Puccio AM, et al. The impact of previous traumatic brain injury on health and functioning: a TRACK-TBI study. J Neurotrauma. 2013;30(24):2014–20. doi:10.1089/neu.2013.3049.
16. *The Merriam-Webster Dictionary*. Springfield, MA: Merriam-Webster, Inc.; p. 720p.
17. COVID-19's impact felt by researchers. [accessed 2023 Feb 20]. https://www.apa.org/science/leadership/students/covid-19-impact-researchers.
18. CDE Catalog | NINDS Common Data Elements. [accessed 2023 Sep 5]. : https://www.commondataelements.ninds.nih.gov/cde-catalog
19. NOT-OD-15-089: Racial and Ethnic Categories and Definitions for NIH Diversity Programs and for Other Reporting Purposes. [accessed 2023 Feb 20]. https://grants.nih.gov/grants/guide/notice-files/not-od-15-089.html
20. Asken BM, Bauer RM, Guskiewicz KM, McCrea MA, Schmidt JD, Giza CC, Snyder AR, Houck ZM, Kontos AP, McAllister TW, 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):1465–74. doi:10.1177/0363546518757984.
21. 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):329–35. doi:10.4085/1062-6050-51.5.02.
22. Master CL, Katz BP, Arbogast KB, McCrea MA, McAllister TW, Pasquina PF, Lapradd M, Zhou W, Broglio SP. Differences in sport-related concussion for female and male athletes in comparable collegiate sports: a study from the NCAA-DoD Concussion Assessment, Research and Education (CARE) consortium. Br J Sports Med. 2021;55(24):1387–94. doi:10.1136/bjsports-2020-103316.
23. Lempke LB, Schmidt JD, Lynall RC. Athletic trainers' concussion-assessment and concussion-management practices: an update. J Athl Train. 2020;55(1):17–26. doi:10.4085/1062-6050-322-18.
24. Buckley TA, Burdette G, Kelly K. Concussion-management practice patterns of national collegiate athletic association division ii and iii athletic trainers: how the other half lives. J Athl Train. 2015;50(8):879–88. doi:10.4085/1062-6050-50.7.04.
25. McGuine TA, Pfaller AY, Post EG, Hetzel SJ, Brooks A, Broglio SP. The influence of athletic trainers on the incidence and management of concussions in high school athletes. J Athl Train. 2018;53(11):1017–1024. doi:10.4085/1062-6050-209-18.
26. Broglio SP, McAllister T, Katz BP, LaPradd M, Zhou W, McCrea MA, Hoy A, Hazzard JB, Kelly LA, DiFiori J, et al. The natural history of sport-related concussion in collegiate athletes: findings from the NCAA-DoD CARE consortium. Sports Med. 2022;52(2):403–15. doi:10.1007/s40279-021-01541-7.
27. Wasserman EB, Kerr ZY, Zuckerman SL, Covassin T. Epidemiology of sports-related concussions in national collegiate athletic association athletes from 2009-2010 to 2013-2014: symptom prevalence, symptom resolution time, and return-to-play time. Am J Sports Med. 2016;44(1):226–33. doi:10.1177/0363546515610537.
28. Chandran A, Boltz AJ, Morris SN, Robison HJ, Nedimyer AK, Collins CL, Register-Mihalik JK. Epidemiology of concussions in National Collegiate Athletic Association (NCAA) sports: 2014/15-2018/19. Am J Sports Med. 2022;50(2):526–36. doi:10.1177/03635465211060340.
29. NCAA Demographic Database [Internet]. 2021. https://www.ncaa.org/sports/2018/12/13/ncaa-demographics-database.aspx.