Bridging Baseline Assessment and Injury Surveillance: A Three-Study Examination of Sport-Related Concussion Monitoring in Canadian Post-Secondary Sport

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Abstract

Background: Sport-related concussion (SRC) surveillance in Canadian post-secondary sport remains fragmented, limiting the ability of institutions to accurately characterize injury risk, recovery trajectories, and academic consequences. Existing systems tend to emphasize isolated components of concussion monitoring, such as pre-season baseline assessment or injury documentation, without integrating athlete-exposure (AE) data or educational outcomes, constraining epidemiologic interpretation and institutional decision-making.

Purpose: This dissertation examined how differences in concussion surveillance structure influence the interpretation of SRC risk, recovery, and academic impact within Canadian post-secondary athletics. The three-study program aimed to (1) characterize baseline and historical concussion features among university athletes, (2) quantify exposure-adjusted incidence and post-injury outcomes in post-secondary sport, and (3) synthesize findings across systems to inform a harmonized concussion surveillance framework.

Methods: Study 1 analyzed pre-season baseline data from university athletes participating in the Varsity Student-Athlete Data Analytics Research (VADAR) program, examining concussion history, baseline symptom presentation, and self-reported recovery duration. Study 2 evaluated retrospective injury surveillance data from Ontario Colleges Athletic Association (OCAA) athletes, incorporating AE-adjusted incidence rates, recovery duration, and documented academic accommodations. Study 3 employed a comparative analytic approach to examine differences in exposure measurement, recovery tracking, and academic outcome reporting across post-secondary surveillance systems.

Results: In Study 1, 43.1% of female and 30.9% of male athletes reported a prior concussion, and female athletes were more than twice as likely to experience recovery lasting longer than 28

days (OR = 2.29, 95% CI [1.26, 4.18]). Study 2 demonstrated that sport-specific risk interpretations shifted substantially when AE denominators were applied, particularly among contact sports. Although female athletes represented 58.2% of diagnosed concussions, no significant sex difference in recovery duration was observed, and nearly half of documented concussions required formal academic accommodations.

Conclusion: Surveillance design is a primary determinant of interpretability in post-secondary concussion research. Integrating baseline measures, exposure-adjusted incidence, and academic recovery indicators enhances understanding of SRC and supports decision-making across institutional, clinical, and team-level contexts. These findings inform evidence-based recommendations for a unified concussion surveillance framework tailored to Canadian post-secondary sport.

Dedication

This dissertation is dedicated to my son, Owen Tablon-Modica, who has brought so much joy, purpose, and perspective to my life. Your curiosity and spirit inspire me every day. You are a reminder of why I kept going, even when the journey felt overwhelming. I hope this work shows you that with perseverance, sacrifice, and belief in yourself, you can achieve things that once felt out of reach.

To my wife, Paula Tablon Modica, this dedication belongs to you as much as it does to anyone. You stood beside me through my master's degree and my PhD, through the stress, the long nights, the doubt, and the sacrifices that came with all of it. You supported me in every way a person can support someone they love, and you never stopped believing in me. When I was tired, you gave me strength. When I questioned myself, you gave me confidence. When this path demanded so much of us, you kept us moving forward. I would not be here without you, and this achievement is as much yours as it is mine.

I also dedicate this work to the memory of my parents, Joy Halenda and Michele Modica. They may not have had the opportunity to pursue higher education, but they gave me something far more important: the values, strength, and determination that carried me here. Their sacrifices created opportunities for me that they never had for themselves, and that is something I carry with deep gratitude.

This dissertation is more than the end of a degree. It is a reflection of the love, sacrifice, and unwavering support of the people who made this journey possible.

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Abbreviations

ANOVA	Analysis of Variance
B	Logistic regression coefficients
CAT(C)	Certified Athletic Therapist (Canada)
CI	Confident Intervals
CISG	Concussion in Sport Group
IR	Incidence Rate
mBESS	modified Balance Error Scoring System
MDS	Minimum Data Set
MOI	Mechanism of Injury
NCAA	National Collegiate Athletic Association
NCAA-ISP	National Collegiate Athletic Association - Injury Surveillance Program
OCAA	Ontario Colleges Athletic Association
OR	Odds ratio
PHC	Previous History of Concussions
PPCS	Persistent post-concussion symptoms
RHOC	Reported History of Concussion
RTL	Return-to-learn
RTP	Return-to-play
SAC	Standardize Assessment of Concussion
SCAT 5	Sport Concussion Assessment Tool 5th Edition
SCAT 6	Sport Concussion Assessment Tool 6th Edition
SD	Standard Deviation
SE	Standard Error
SRC	Sport related concussion
VADAR	Varsity Athlete Data Analysis Research

Chapter 1. General Introduction

Overview and Research in Context

Sport-related concussion (SRC) is routinely described as a priority injury in post-secondary sport, yet the empirical foundation required to meaningfully characterize its burden, risk distribution, and functional impact remains underdeveloped in the Canadian context (Black et al., 2017; Emery et al., 2017). Despite substantial growth in concussion awareness, policy, and clinical guidance over the past decade, Canadian post-secondary sport continues to rely on fragmented, institution-specific data systems that limit both internal validity and cross-context comparability (Emery et al., 2017). As a result, much of what is known about concussion in this population was based on isolated baseline cohorts, or retrospective injury reports that lack exposure normalization, longitudinal integration, or academic outcome data (Kerr et al., 2014).

This fragmentation represents a structural problem rather than a simple gap in evidence. Concussion epidemiology is inherently dependent on surveillance quality: without consistent injury definitions, standardized data elements, and exposure-adjusted denominators, estimates of incidence, recovery, and risk stratification become difficult to interpret (Bahr et al., 2020a; Bahr & Krosshaug, 2005; Finch, 1997a). While international surveillance models, most notably those developed within the National Collegiate Athletic Association (NCAA) demonstrate the value of centralized, exposure-based systems (Chandran, Boltz, et al., 2021; Chandran et al., 2024; Kerr, Register-Mihalik, et al., 2014; Kontos et al., 2024), no comparable framework exists for Canadian post-secondary sport (Bang et al., 2020; Emery et al., 2017). Consequently, concussion research in this setting often proceeds without consistent definition and the methodological infrastructure necessary to distinguish true injury risk from participation volume, reporting behavior, or institutional variability (Bahr et al., 2020a; Finch, 2006).

Within post-secondary settings, concussion research has predominantly emphasized pre-season baseline assessments, symptom inventories, and concussion history (Echemendia et al., 2017; Kontos et al., 2013). These types of data provide insight into athlete-level vulnerability entering competition, but they are typically disconnected from subsequent injury occurrence, exposure patterns, and post-injury outcomes (Lynall et al., 2022). Conversely, post-secondary sport datasets tend to prioritize post-injury reporting and clinical recovery timelines, frequently in the absence of baseline profiles or standardized exposure metrics (Bovard, 2008; Maerlender et al., 2016). When examined independently, neither approach is sufficient to characterize concussion risk across the athlete lifecycle. Baseline symptom reporting without injury context risks overinterpreting vulnerability, while post-injury case counts without denominators risk misrepresenting sport-specific risk (Bahr & Krosshaug, 2005; Kerr, Register-Mihalik, et al., 2014).

Sex-based differences further complicate concussion surveillance. In this context, "sex" refers to biological classification (e.g., male, female), whereas "gender" reflects socially constructed roles, identities, and behaviors that may influence sport participation, reporting patterns, and access to care. The datasets used in this dissertation classify athletes based on sex as recorded in institutional or team-based records, and do not capture gender identity; therefore, interpretations of sex-based differences should be understood within these measurement constraints. Female athletes consistently report higher concussion incidence and greater symptom duration than male athletes in sex-comparable sports (Bretzin et al., 2021; Covassin et al., 2016), yet the extent to which these patterns reflect biological vulnerability, differential exposure, reporting behavior, or structural features of sport systems remains unclear (Bretzin et al., 2018; Cheng et al., 2019; Meier et al., 2015; Wallace et al., 2017). This limitation is

particularly relevant within Canadian post-secondary sport, where female participation has expanded rapidly in the absence of parallel investment in standardized data infrastructure (Emery et al., 2017).

Sport classification presents a similar challenge. Collision sports are commonly identified as high risk for concussion; however, emerging evidence suggests that several contact and non-contact sports contribute substantially to overall concussion symptom severity when participation volume is considered (Bretzin et al., 2021; Kerr, Register-Mihalik, et al., 2014). Reliance on sport contact categories alone obscures meaningful variation in exposure, style of play, and institutional context (Finch, 2006). In the absence of athlete-exposure (AE) data, surveillance systems may conflate high participation with high risk, undermining prevention efforts and resource allocation (Bahr et al., 2020a; Bahr & Krosshaug, 2005; Chandran, Boltz, et al., 2021).

Beyond athletic participation, concussion has demonstrable academic consequences that are inconsistently captured within existing surveillance models. Cognitive symptoms commonly associated with SRC such as impairments in attention, memory, and processing speed have direct implications for academic functioning (Giza & Hovda, 2001; Halstead et al., 2013; McAvoy et al., 2020). Although return-to-learn (RTL) has gained recognition as a core component of concussion management, academic outcomes such as missed classes, examination deferrals, and formal accommodations are rarely integrated into post-secondary concussion datasets (McAvoy et al., 2020; Sady et al., 2011). This omission reinforces a narrow, sport-centric conceptualization of recovery and fails to reflect the primary educational mandate of post-secondary institutions.

Taken together, these limitations underscore the need to reexamine concussion research in Canadian post-secondary sport as a surveillance problem rather than a purely clinical one (Emery et al., 2017; Finch, 1997a). Addressing this challenge requires data systems capable of linking

baseline vulnerability, exposure-adjusted injury occurrence, symptom duration, and academic impact across institutional contexts (Chandran, Morris, et al., 2021; Kerr, Register-Mihalik, et al., 2014; Morris et al., 2021). Without such integration, concussion research remains largely descriptive, and policy development remains constrained by incomplete and non-comparable evidence (Finch, 2006).

Purpose and Structure of the Dissertation

The purpose of this dissertation is to address existing critical limitations in Canadian post-secondary concussion research by critically examining SRC through a surveillance-oriented lens. Specifically, this work aims to characterize pre-season baseline profiles, injury occurrence, recovery patterns, and functional academic impact using complementary datasets drawn from university and college sport environments. By integrating findings across these contexts, this dissertation evaluates the extent to which existing data systems can support interpretable concussion epidemiology and identifies key characteristics to promote a more informative and standardized national surveillance system. Across all studies, sex is operationalized based on classification within institutional or team-based records and therefore reflects the available surveillance variable rather than a comprehensive measure of gender identity.

This dissertation is organized as three interrelated studies, each addressing distinct characteristics and limitations within the current surveillance landscape:

- Study 1 examines concussion history and pre-season symptom profiles among Canadian university student-athletes using standardized pre-season baseline assessment data. The objective of this study is to characterize athlete-level symptoms and performance indicators entering competition and to evaluate sex-based differences in pre-season

baseline symptom reporting and prior concussion exposure. This study provides a descriptive account of pre-season symptom profiles and prior concussion exposure, highlighting both the interpretive value and the limitation of baseline data in the absence of exposure-adjusted injury outcomes.

- Study 2 analyzes SRC data collected through a multi-year injury surveillance system within Ontario college student-athletes. This study focuses on sex-specific concussion patterns, incidence by sport, symptom duration, and post-injury academic accommodations. By incorporating AE estimates, this study addresses key limitations of raw injury counts and provides a more accurate representation of concussion symptom duration across sports and sexes.
- Study 3 integrates findings from Studies 1 and 2 to evaluate similarities and differences between university and college datasets. The objective of this study is to identify methodological inconsistencies, data gaps, and structural barriers to comparability, and to propose a standardized Minimum Data Set (MDS) for concussion surveillance in Canadian post-secondary sport. This final study emphasizes surveillance feasibility, data standardization, and policy relevance rather than injury prediction.

Collectively, these studies extend concussion research beyond isolated descriptions of baseline assessment and injury occurrence by demonstrating the value of a more integrated surveillance perspective in Canadian post-secondary sport. They also provide a foundation for improving how concussion data are interpreted, compared, and ultimately used to support prevention, clinical management, and institutional decision-making.

Chapter 2. An Analysis of Post-Secondary Student-Athlete Baseline Concussion Reporting Across 2019, 2022, and 2023 at a Canadian University

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Abstract

Background: SRC remains an under-characterized injury among Canadian post-secondary student-athletes. Baseline symptom reporting, concussion history, and sex-based differences in recovery trajectories are insufficiently described in this population despite growing evidence that these variables influence SRC outcomes.

Objective: To examine differences in concussion history, sex, and sport type and their associations with concussion symptom reporting and recovery time in post-secondary student-athletes.

Methods: This cross-sectional study analyzes pre-season baseline concussion assessments collected in 2019, 2022, and 2023 at York University as part of the VADAR Program. The cohort includes 701 post-secondary student-athletes (353 males, 348 females) from 14 sports, stratified by contact level (collision, contact, non-contact). History of concussion, number of prior concussions, recovery duration from the most recent concussion, and years since injury were obtained via standardized self-report questionnaires completed immediately prior to pre-season baseline testing. Baseline symptom reporting was measured using the SCAT5 (2019, 2022) or SCAT6 (2023) graded symptom checklist. Time to recovery from the most recent concussion was the primary outcome. Statistical analyses included descriptive statistics, independent-samples *t*-tests, chi-square tests, one-way ANOVA or Kruskal–Wallis tests, and logistic regression to identify predictors of prolonged recovery (>28 days).

Results: Overall, 36.4% of athletes reported a history of concussion (RHOC), with females reporting higher prevalence than males (43.1% vs 30.9%, $p = .003$). The largest proportion of RHOC athletes (48.2%) participated in collision sports. Female athletes reported longer recovery

times (M = 45.24 days ± 61.94) compared to males (M = 39.68 ± 58.27). Logistic regression identified sex as a significant predictor of persistent post-concussion symptoms (>28 days; OR 2.29, p = .007). Analysis of Variance (ANOVA) demonstrated significant differences in baseline concussion symptom severity across sex by year groups (p < .001). Contact sport athletes with RHOC showed the longest recovery durations, while collision sport athletes had the highest proportion of longer symptom duration.

Conclusions: Female sex, collision sport participation, and prior concussion exposure were associated with higher pre-season baseline symptom reporting and prolonged recovery following SRC. These findings support the need for sex- and sport-specific SRC surveillance and return-to-play (RTP) strategies in Canadian post-secondary athletics.

Introduction

SRC is one of the most prevalent injuries in post-secondary athletics and remains a major public health concern due to its association with prolonged recovery, cumulative neurological burden, and long-term sequelae (Giza & Hovda, 2001; Guskiewicz et al., 2003; Iverson et al., 2017; Kamins et al., 2017; McPherson et al., 2019). A previous history of concussion (PHC) is consistently identified as one of the strongest predictors of future SRC, as well as increased baseline concussion symptom severity, and delayed recovery (Gaudet et al., 2022; Guskiewicz et al., 2003; Iverson et al., 2017; Liao et al., 2026; McPherson et al., 2019). Athletes with one or more prior concussions have a two to five times increased risk of recurrent injury, a vulnerability attributed to neurometabolic, axonal, and cerebrovascular alterations that persist beyond clinical symptom resolution (Giza & Hovda, 2001; Kamins et al., 2017). Recurrent SRC is also associated with cumulative cognitive deficits, and in some cases, long-term neurodegenerative risk (Eierud et al., 2014; Montenigro et al., 2017; Stein et al., 2015).

Sex differences in concussion epidemiology are widely reported. Female athletes experience higher concussion incidence, report greater baseline concussion symptom severity, and exhibit longer recovery durations than male athletes (Bazarian et al., 2010; Brown et al., 2015; Comeau et al., 2023; Konstantinides et al., 2024; Sunderland et al., 2024). Hormonal profiles, biomechanical factors such as reduced neck strength, and differences in reporting behavior have been proposed as mechanisms underlying these disparities (Garrett et al., 2023; Kay et al., 2023; Wallace et al., 2017). Female athletes often endorse a greater number of cognitive, emotional, and somatic symptoms at both baseline and post-injury time points, including headaches, dizziness, emotional disturbances, and cognitive slowing (Brown et al.,

2015). These sex-based variations highlight the need for sex-specific evaluation and management strategies.

Sport type also contributes to SRC risk. Collision sports such as football, rugby, and ice hockey consistently demonstrate the highest SRC incidence and PHC symptom severity (Collie et al., 2006; Konstantinides et al., 2024; Shill et al., 2025), primarily due to frequent high-magnitude impacts and repetitive head contact. Athletes in collision sports accumulate substantial sub-concussive exposure, which may influence later symptom expression and recovery duration (Montenigro et al., 2017). Contact sports, such as basketball or soccer, while involving less frequent high-impact collisions, still carry significant risk for SRC through player-to-player and player-to-object interactions. Non-contact sports, such as tennis or volleyball, generally show lower SRC incidence but are not risk-free; concussions still occur through falls, accidental impacts, or equipment-related mechanisms.

Despite increasing recognition of SRC in post-secondary sport, Canadian post-secondary athletes remain underrepresented in the literature. Many studies rely on small samples, focus on single sports, or examine professional or high school athletes rather than post-secondary aged populations (Brown et al., 2015). Baseline symptom reporting is important for individualized post-injury comparison , yet it is inconsistently described in Canadian cohorts (Jorgensen et al., 2017; Lynall et al., 2022; Yang et al., 2017). Furthermore, little is known about how concussion history, sex, and sport participation may interact to influence recovery duration, symptom patterns, or risk of persistent post-concussion symptoms (PPCS).

The VADAR program at York University was established in 2019 as a long-term, multi-faceted initiative to address these gaps by characterizing the heterogeneous features of SRC in university varsity student-athletes using a comprehensive baseline assessment battery. Developed

under the direction of Dr. Lauren Sergio in collaboration with researchers across the Faculty of Health and the athletic therapy staff of the Athletics & Recreation Department, VADAR was supported by funding from the Canadian Institutes of Health Research (CIHR) for baseline testing of neurocognitive and neuromuscular variables in varsity athletes. The pre-season baseline protocol comprises a mandatory component, completed by all rostered varsity student-athletes, consisting of the Sport Concussion Assessment Tool (SCAT5/SCAT6) and a standardized demographic and medical history intake. Athletes were also invited to voluntarily participate in additional neurocognitive and neuromuscular assessments including force-plate postural sway, Doppler ultrasound cerebral blood flow, cognitive-motor integration tasks, oculomotor performance, and executive function testing, generating comprehensive baseline profiles for individualized post-injury comparison (Echemendia et al., 2017; Patricios et al., 2023).

Objective

To examine the association between sex, sport-type, and concussion history, pre-season concussion symptom reporting and recovery duration among Canadian post-secondary student-athletes.

Methods

This study used a cross-sectional design to analyze pre-season baseline concussion assessments collected in 2019, 2022, and 2023 at York University as part of the VADAR program. The 2020–2021 season was excluded because the COVID-19 pandemic led to the suspension of intercollegiate sport and widespread disruption to athletic participation and injury surveillance (Wiltshire et al., 2022). The VADAR Consortium consisted of collaborations with the Whiplash and Head Injury Prevention/Rehabilitation (WHIPR) Lab, the Motor Control Lab,

the Dynamic Balance Lab, and the York University Sport Medicine Team. Another goal of the program was to create a normative baseline dataset for comparison against post-concussion data at acute, interim, and RTS and RTL timepoints for varsity athletes who did not have individual baseline data in the additional neurocognitive and neuromuscular variables. The analyses presented in this study draw exclusively from the mandatory SCAT5/SCAT6,demographic and medical history intake components to ensure consistent data availability across the full cohort.. All procedures received approval from the York University Research Ethics Board (Certificate #: e2019-283), and written informed consent was obtained from all participants.

Study Population

The study sample consisted of 701 varsity student-athletes (353 males, 348 females) representing 14 sports. Athletes were at least 17 years of age, rostered on a varsity team during the relevant competitive season, and completed the full pre-season baseline concussion testing protocol. Athletes that reported previous concussion history were included provided they were not experiencing ongoing injury-related symptoms at the time of testing. Individuals were excluded if they reported unresolved concussion symptoms, were actively recovering from a recent concussion, reported a current lower-extremity musculoskeletal injury that might influence balance test performance, or failed to complete required demographic or clinical questionnaires.

Participating sports included men's and women's soccer, basketball, ice hockey, and volleyball; men's football; women's rugby and field hockey; and co-ed wrestling, cross-country, track and field, and tennis. Athletes were further stratified by sport type collision, contact, or non-contact based on widely used classification systems in SRC literature (Collie et al., 2006; Shill et al., 2024).

Data Collection

Baseline assessments were conducted in person at the Goreman/Shore Sport Injury Clinic prior to each competitive season as part of the pre-season participation protocol jointly administered by the VADAR Consortium and the athletic therapy staff of the Athletics & Recreation Department. Testing sessions were administered by Certified Athletic Therapists (Canada) [CAT(C)], graduate students trained in concussion assessment procedures, and research staff, all of whom followed standardized VADAR Consortium protocols to ensure consistency across years. The mandatory SCAT5/SCAT6 evaluation and demographic intake were completed by all participating athletes, while the additional neurocognitive and neuromuscular components of the broader VADAR battery were completed on a voluntary basis and are not included in the present analysis.

Athletes first completed a demographic and medical history questionnaire that included age, sex, sport, injury history, number of previously diagnosed concussions, years since the most recent concussion, and recovery time following their most recent concussion. Participants then completed the Sport Concussion Assessment Tool (SCAT5 in 2019 and 2022; SCAT6 in 2023) off-field evaluation (Echemendia et al., 2017; McCrory et al., 2017; Patricios et al., 2023). Following this, cognitive testing and balance assessment were conducted using the Standardized Assessment of Concussion (SAC) and the modified Balance Error Scoring System (mBESS). Athletes also underwent a brief neurological examination that included cervical spine range of motion testing, vestibulo-ocular screening, coordination tasks, and tandem gait. All procedures were administered according to the standardized scoring instructions outlined in the SCAT manuals and international concussion consensus statements (Echemendia et al., 2017; Patricios et al., 2023).

Measures

All variables included in the statistical analyses were obtained from the mandatory pre-season demographic and medical intake questionnaire and from athletes' SCAT5 or SCAT6 baseline assessments (Echemendia et al., 2017; Patricios et al., 2023). These instruments were completed immediately prior to baseline testing which was then administered by trained research personnel following standardized VADAR program protocols. Sex was self-reported as male or female and used as a demographic grouping variable in all analyses.

History of Concussion

History of concussion was assessed through self-report on the demographic intake form. Athletes indicated whether they had ever sustained a concussion diagnosed by a licensed healthcare professional. Responses were coded dichotomously (0 = no prior concussion; 1 = one or more diagnosed concussions). This method is consistent with established epidemiological surveillance protocols and demonstrates acceptable reliability in post-secondary athlete populations (Bruce & Echemendia, 2009; Covassin et al., 2016). Athletes also reported the total number of previously diagnosed concussions (0, 1, 2, 3, or ≥4). This variable was summarized descriptively and treated as categorical or continuous depending on analytic requirements. Missing values were retained and reported in associated tables.

Recovery Time From the Most Recent Concussion

For athletes reporting at least one prior concussion, recovery duration from the most recent injury was collected through self-report. Athletes indicated the number of days required to return to full, symptom-free activity following their last medically diagnosed concussion. This variable was analyzed both as a continuous measure (days) for descriptive statistics, and as a

categorical variable reflecting clinically recognized recovery trajectories. Recovery categories included 0 days (immediately asymptomatic), 1–7 days, 8–14 days, 15–21 days, 22–28 days, and >28 days, consistent with international concussion consensus definitions distinguishing normal from prolonged recovery (Leddy, et al., 2017; Nelson et al., 1984; Patricios et al., 2023). Persistent recovery was defined as symptom duration exceeding 28 days following the most recent concussion, consistent with contemporary concussion consensus literature distinguishing typical recovery trajectories from prolonged symptom presentation in adult populations (Leddy et al., 2023; Nelson et al., 1984; Patricios et al., 2023). Athletes also reported the number of years since their most recent concussion (0, 1, 2, 3, or ≥4 years), which permitted characterization of the recency of injury within the cohort.

Sport Type and Contact Level Classification

Sport participation was determined from institutional rosters and categorized according to internationally validated contact-level definitions. Each sport was classified as collision, contact, or non-contact based on the degree and frequency of anticipated physical contact inherent to gameplay. This classification system is frequently used in concussion epidemiology and supports meaningful comparisons across sport types (Collie et al., 2006; Shill et al., 2024, 2025).

Baseline Concussion Symptom Severity

The total baseline symptom severity score was obtained from pre-season baseline assessment for all included athletes. This score quantifies the athlete's current symptom state at the time of testing. Concussion symptom severity was quantified as the total SCAT symptom severity score, calculated by summing ratings (0 [none] to 6 [severe]) for each of the 22 symptoms, resulting in a total score ranging from 0 to 132 (Echemendia et al., 2017; Patricios et

al., 2023). Pre-season concussion symptom reporting was operationalized as the total number of symptoms endorsed (score >0), capturing the breadth of symptom experience. Both measures were analysed as primary outcomes examining differences across sex, sport type, and concussion history.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 29. Descriptive statistics (means, standard deviations, frequencies, and percentages) summarized demographic characteristics, concussion history variables, symptom scores, and recovery time. Group differences by sex, sport type, and concussion history were evaluated using independent-samples *t*-tests for continuous variables and chi-square tests for categorical variables. When comparing across more than two groups, one-way ANOVA was used for normally distributed variables, while Kruskal–Wallis tests were used when distributions violated normality assumptions.

Logistic regression models were used to identify factors associated with prolonged recovery (>28 days), with sex, sport type, and concussion history included as independent variables. Odds ratios and 95% confidence intervals were reported. Missing data were handled using pairwise deletion, and patterns of missingness were assessed to ensure no systematic bias.

Results

Demographic Characteristics

Descriptive statistics for the varsity student-athlete sample are presented in **Table 1**. A total of 701 athletes (353 male, 348 female) completed baseline assessments. Ages ranged from 17 to 31 years (M = 19.84, SD = 1.85). A total of 255 athletes (36.4%) reported a history of concussion, with females reporting a higher proportion (43.1%) compared to males (30.9%).

Within athletes reporting concussion history, 19.5% had one, 10.6% had two, 4.1% had three, and 1.7% reported more than four previous concussions. Missing data were present for 15.8% of responses.

The average number of previously diagnosed concussions was higher among females (M = 0.89, SD = 1.17) than males (M = 0.55, SD = 0.89). Recovery times for the most recent concussion ranged from 0 to >28 days, with most athletes recovering within 14 days. Overall, 30.6% of athletes with a concussion history reported prolonged recovery (>28 days). Recovery time data were missing for 22% of participants with a reported history of concussion.

Table 1. Comparative Sex-Based VADAR Program Descriptive Statistics for University Varsity Student-Athletes From 2019, 2022, and 2023 Pre-season Baselines ($N = 701$)

Characteristic	Male ($n = 353$)	Female ($n = 348$)	Total ($n = 701$)
Age, mean ± SD (range)	19.9 ± 1.9 (17-25)	19.8 ± 1.8 (17-31)	19.8 ±1.9 (17-31)
Reported history of concussion (RHOC) n (%)	105 (30.9)	105 (43.1)	255 (37.1)
Number of previously diagnosed concussions, n (%)			
0	182 (51.6)	156 (44.8)	338 (48.2)
1	63 (17.8)	74 (21.3)	137 (19.5)
2	26 (7.4)	48 (13.8)	74 (10.6)
3	10 (2.8)	19 (5.5)	29 (4.1)
>4	2 (0.6)	10 (2.8)	12 (1.7)
Missing data	70 (19.8)	41 (11.8)	111 (15.8)
# of previously diagnosed concussions, *M* ± *SD* (range)	0.6 ±0.9 (0 – 6)	0.9 ± 1.2 (0 – 7)	0.73 ± 1.1 (0 – 7)
Recovery time of most recent concussion, n (% of athletes with a RHOC)			
Normal (1 – 14 days)	50 (47.6)	48 (32.0)	98 (38.4)
Extended (15 – 28 days)	9 (8.6)	14 (9.3)	23 (9.0)
PPCS (>29 days)	24 (22.9)	54 (36.0)	78 (30.6)
Missing data from recovery time of most recent concussion	22 (21.0)	34 (22.7)	56 (22.0)
Recovery time of most recent concussion (days), *M*, ± *SD*	1.7 ± 0.9	2.1 ± 0.9	1.9 ± 0.9

Note. Abbreviations: RHOC, reported history of concussion; PPCS, Persistent post-concussion symptoms.

Sport Participation

Sport participation data were available for 684 athletes (340 male, 344 female) and are presented in **Table 2**. Collision sports accounted for 37.5% of total participation, followed by contact sports (39.7%) and limited/non-contact sports (22.6%). Among males, football

represented the largest group (13.4%), followed by men's soccer and basketball. Among females, rugby (9.3%) and women's ice hockey (8.3%) had the highest participation.

Concussion history differed substantially across sport types. Collision sports accounted for nearly half (48.2%) of all athletes with RHOC, compared with 34.2% of those without. Contact sports comprised 34.1% of RHOC athletes and 40.4% of those without, while non-contact sports had the lowest representation among RHOC athletes (17.6%). Women's rugby and women's ice hockey showed the highest proportions of athletes reporting prior concussions among females; men's football and men's ice hockey accounted for the highest proportions among males.

Separate chi-square analyses were conducted to examine the association between sport and concussion history. Across these analyses, a significant association was observed($p < 0.001$), indicating that concussion history was not evenly distributed across sports. Collision-intensive and high-contact sports demonstrated elevated prevalence of concussion history, consistent with prior literature.

Table 2. Number (%) of University Student-Athletes Participating in Each Varsity Sport, Stratified by sex (n = 684)

Sport	Male (n = 340)	Female (n = 344)	Total (n = 684)
Collision sports			
Men's Football	92 (13.4)	-	92 (13.4)
Men's ice hockey	44 (6.3)	-	44 (6.3)
Women's ice hockey	-	57 (8.3)	57 (8.3)
Women's rugby	-	64 (9.3)	64 (9.3)
All collision sports	136 (19.4)	121 (17.2)	257 (37.5)
Contact sports			
Men's soccer	76 (10.8)	-	76 (11.0)
Women's soccer	-	48 (6.8)	48 (7.0)
Men's basketball	44 (6.3)	-	44 (6.4)
Women's basketball	-	30 (4.3)	30 (4.3)
Women's field hockey	-	51 (7.3)	51 (7.3)
Wrestling	16 (4.5)	7 (2.0)	23 (3.3)
All contact sports	136 (21.6)	90 (20.4)	272 (39.7)
Limited contact/non-contact sports			
Men's volleyball	25 (3.6)	-	25 (3.6)
Women's volleyball	-	42 (6.0)	42 (6.0)
Track and field	33 (9.3)	32 (9.2)	65 (9.4)
Cross-country	3 (0.8)	6 (1.7)	9 (1.3)
Tennis	7 (2.0)	7 (2.0)	14 (2.0)
All limited contact/non-contact sports	68 (15.7)	87 (18.9)	155 (22.6)

Concussion History Across Sport Types

Among athletes with available sport participation, 255 (36.3%) reported a history of concussion (**Table 3**). Collision sports accounted for the largest proportion of athletes with a RHOC, followed by contact and non-contact sports.

For example, men's football was associated with 43 of the 255 athletes with RHOC (16.9%) reported a concussion, compared to 45 of 339 athletes without RHOC (13.3%). Among

female athletes, women's rugby had the highest RHOC prevalence (35 athletes, 13.7%), followed by women's ice hockey (28 athletes, 11.0%).

Table 3. Number (%) of University Student-Athletes Participating in Each Sport Stratified by Concussion History (n = 594)

Sport	No RHOC (n = 339)	RHOC (n = 255)
Collision sports		
Men's Football	45 (13.3)	43 (16.9)
Men's ice hockey	26 (7.7)	17 (6.7)
Women's ice hockey	26 (7.7)	28 (11.0)
Women's rugby	19 (5.6)	35 (13.7)
All collision sports	166 (49.0)	123 (48.2)
Contact sports		
Men's soccer	30 (8.8)	14 (5.5)
Women's soccer	27 (8.0)	18 (7.1)
Men's basketball	28 (8.3)	13 (5.1)
Women's basketball	14 (4.1)	15 (5.9)
Women's field hockey	11 (3.2)	7 (2.7)
Wrestling	27 (8.0)	20 (7.8)
All contact sports	137 (40.4)	87 (34.1)
Limited contact/non-contact sports		
Men's volleyball	16 (4.7)	7 (2.7)
Women's volleyball	16 (4.7)	24 (9.4)
Track and field	42 (12.4)	10 (3.9)
All limited contact/non-contact sports	86 (25.3)	45 (17.6)

Note. Abbreviations: No RHOC, no reported history of concussion; RHOC, reported history of concussion.

Recovery Duration and Predictors of Persistent Symptoms

Among athletes with RHOC, recovery time from the most recent concussion varied widely. Overall, 38.4% of athletes recovered within 14 days, 9.0% recovered within 15–28 days, and 30.6% experienced persistent symptoms beyond 28 days. Recovery data were missing for 22.0% of athletes with RHOC, a limitation addressed in the discussion but consistent with retrospective concussion research.

As shown in **Table 4**, a logistic regression model evaluating factors associated with persistent symptoms demonstrated that sex was significantly associated with longer recovery: female athletes had 2.29 times the odds of reporting prolonged recovery compared with males ($p = 0.007$). Sport type yielded two significant associations: male athletes in basketball (OR = 4.82, $p = 0.047$) and male volleyball athletes (OR = 7.71, $p = 0.035$) were significantly more likely to experience persistent symptoms relative to football players. Concussion history was not a significant predictor in the model ($p = 0.233$).

Table 4. Odds Ratios for Predictors of Persistent Recovery vs. Normal Recovery

Predictor	*OR*	95% *CI*
Sex (Female)	2.29	1.26-4.18
Sport: Basketball (Male)	4.82	1.02-22.83
Sport: Volleyball (Male)	7.71	1.14-52.33
Concussion History	1.45	0.80-2.62

Note. OR, Odds Ratio; CI, Confidence Interval. Reference groups are indicated in parentheses.

SCAT Symptom Severity

An analysis of baseline concussion symptom severity scores across 2019, 2022, and 2023 revealed notable differences by sport type and sex. Participants in collision sports consistently reported the highest symptom severity scores, with females generally exceeding males in all categories (**Figure 1**).

To statistically assess these observed group differences, a one-way ANOVA was conducted using the combined categories of sex and year (2019-Male, 2019-Female, etc.). The ANOVA revealed a significant effect of group on baseline concussion symptom severity scores ($p < .001$), with a medium-to-large effect size ($\eta^2 = 0.103$).

Post hoc Tukey HSD comparisons further clarified these differences. Female athletes in 2023 reported significantly higher baseline concussion symptom severity scores than all other groups ($p < .001$), followed by 2023 male athletes, whose scores were significantly higher than those of 2019 and 2022 males. The 2022 female group also reported significantly higher scores than the 2019 male group. These comparisons support the conclusion that the increase in reported baseline concussion symptom severity was not only sex-based but also influenced by year, with a particularly marked rise in 2023.

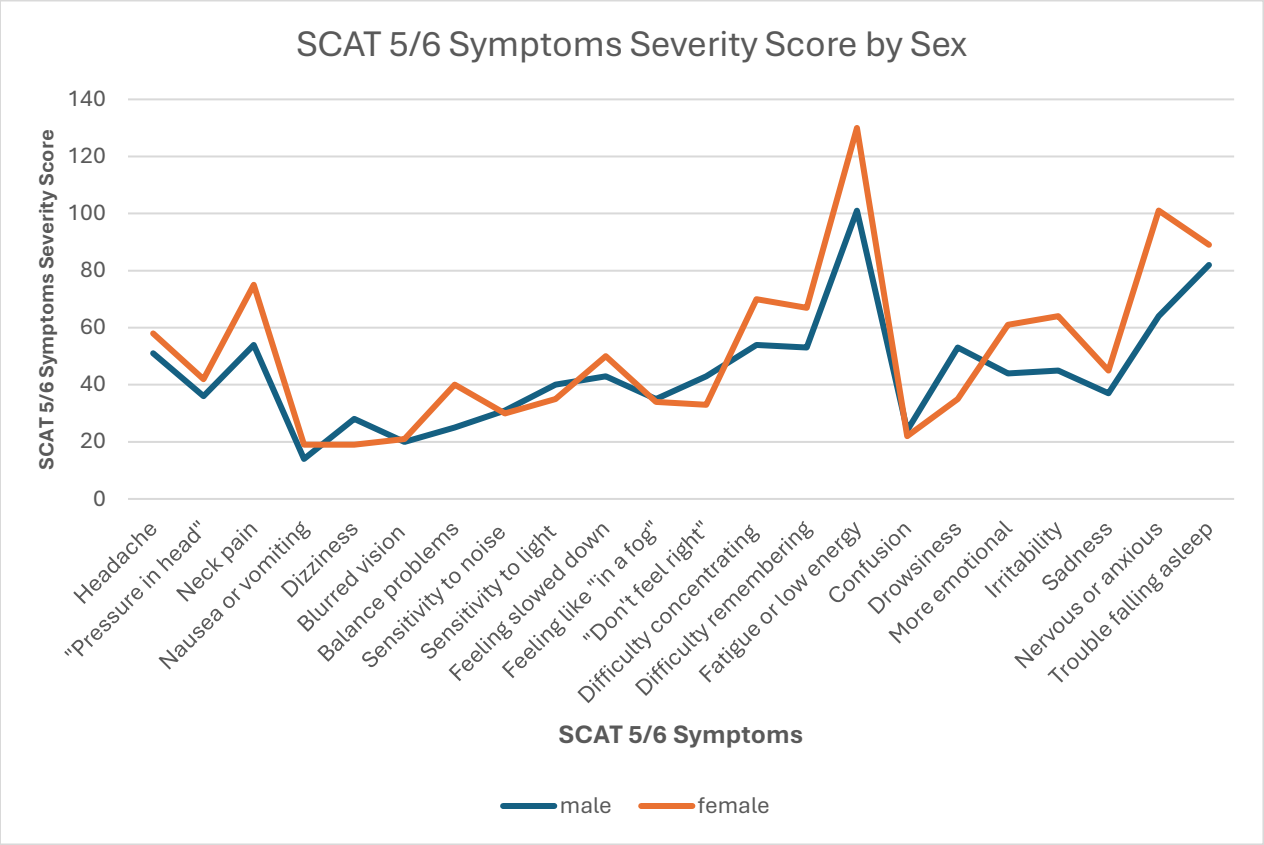


Figure 1. VADAR Program Baseline Concussion Symptom Severity Scores by Sex

Sex-related Differences

Sex-based analyses revealed small-to-moderate differences in baseline concussion symptom severity scores, with females reporting higher baseline concussion symptom severity scores (M = 6.75, SD = 10.67) than males (M = 5.24, SD = 8.93), though this did not reach statistical significance, $t(615) = -1.89$, $p = 0.06$. More detailed symptom-level analyses are presented in **Table 5**.

More robust sex-based differences emerged in recovery outcomes. A chi-square test comparing recovery categories (Normal, Extended, Persistent) by sex was statistically significant, $\chi^2(2) = 15.44$, $p = 0.001$, indicating that females were more likely than males to experience prolonged recovery. Specifically, the proportion of females categorized with persistent symptoms was markedly higher.

Logistic regression further supported these findings, identifying sex as being significantly associated with prolonged recovery. Females were 2.29 times more likely than males to experience persistent post-concussion symptoms ($p = 0.008$).

Table 5. Number (%) of University Varsity-Athletes Reporting baseline SCAT5/SCAT6 Symptoms Stratified by Sex

Symptom	Sex	Athletes Reporting Symptom	χ^2	p	V
Headache	Male (n = 300)	51 (17.0)	2.538	0.864	0.065
	Female (n = 308)	58 (18.8)			
"Pressure in head"	Male (n = 300)	36 (12.0)	3.319	0.506	0.074
	Female (n = 308)	42 (13.6)			
Neck pain	Male (n = 300)	54 (18.0)	5.221	0.265	0.093
	Female (n = 308)	75 (24.3)			
Nausea or vomiting	Male (n = 300)	14 (4.7)	3.044	0.385	0.071
	Female (n = 308)	19 (6.1)			
Dizziness	Male (n = 300)	28 (6.7)	7.030	0.134	0.108
	Female (n = 308)	19 (6.1)			
Blurred vision	Male (n = 300)	20 (6.7)	1.210	0.751	0.045
	Female (n = 308)	21 (6.8)			
Balance problems	Male (n = 300)	25 (8.3)	4.050	0.256	0.082
	Female (n = 308)	40 (12.9)			
Sensitivity to noise	Male (n = 300)	31 (10.3)	2.016	0.847	0.058
	Female (n = 308)	30 (9.7)			
Sensitivity to light	Male (n = 300)	40 (13.3)	5.279	0.509	0.093
	Female (n = 308)	35 (11.3)			
Feeling slowed down	Male (n = 300)	43 (14.3)	3.663	0.453	0.078
	Female (n = 309)	50 (16.2)			
Feeling like "in a fog"	Male (n = 300)	35 (11.7)	3.331	0.504	0.074
	Female (n = 308)	34 (11.0)			
"Don't feel right"	Male (n = 299)	43 (14.3)	3.799	0.434	0.079
	Female (n = 309)	33 (10.7)			
Difficulty concentrating	Male (n = 300)	54 (18.0)	11.623	0.071	0.138
	Female (n = 309)	70 (22.7)			
Difficulty remembering	Male (n = 300)	53 (17.7)	5.068	0.408	0.091
	Female (n = 309)	67 (21.7)			
Fatigue or low energy	Male (n = 299)	101 (33.7)	10.674	0.058	0.133
	Female (n = 308)	130 (42.1)			
Confusion	Male (n = 300)	24 (8.0)	6.364	0.272	0.102
	Female (n = 309)	22 (7.1)			
Drowsiness	Male (n = 300)	53 (17.7)	7.401	0.116	0.110
	Female (n = 309)	35 (11.3)			
More emotional	Male (n = 300)	44 (14.7)	7.662	0.176	0.112
	Female (n = 309)	61(19.7)			
Irritability	Male (n = 300)	45 (15.0)	5.681	0.339	0.097

	Female (n = 309)	64 (20.7)			
Sadness	Male (n = 300)	37 (12.3)	6.657	0.247	0.105
	Female (n = 309)	45 (14.6)			
Nervous or anxious	Male (n = 300)	64 (21.3)	16.370	0.012	0.164
	Female (n = 309)	101 (32.7)			
Trouble falling	Male (n = 300)	82 (27.3)	5.663	0.462	0.096
asleep	Female (n = 309)	89 (28.8)			

Note. $\chi 2$, Pearson's chi-square test; V; Cramer's V effect size.

† Fisher's exact test p value.

Sport-Related Differences

Concussion History by Sport

A chi-square test revealed a significant association between sport type and RHOC ($\chi^2(14) = 40.562$, $p < 0.001$), with collision and contact sports exhibiting the highest prevalence (**Figure 2**). Women's rugby and ice hockey had higher frequencies, whereas non-contact sports had lower frequencies.

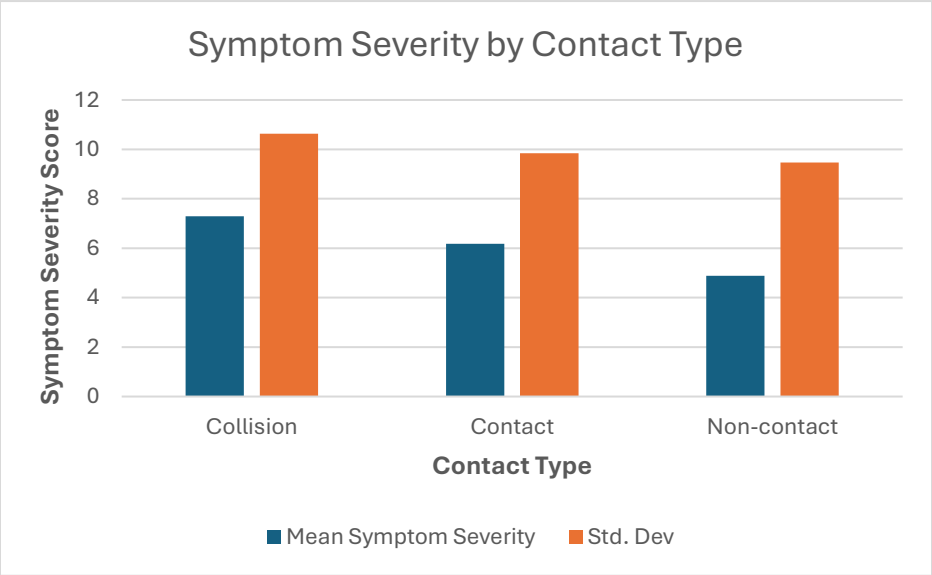


Figure 2. Distribution of SCAT symptom severity scores by sport contact level

Symptom Severity by Sport Contact Level

A sport-specific ANOVA indicated significant differences in baseline concussion symptom severity across individual sports, $F(14, 593) = 2.695$, $p < 0.001$, $\eta^2 = 0.060$. However, broader group-level ANOVA by contact type (collision, contact, non-contact) did not yield statistically significant differences ($F(2, 198) = 0.26$, $p = 0.775$, $\eta^2 = 0.003$; see **Table 6**).

Descriptive means showed slightly higher baseline concussion symptom severity in non-contact sports ($M = 7.75$, $SD = 9.73$), followed by contact ($M = 6.51$, $SD = 9.56$) and collision ($M = 6.41$, $SD = 10.19$). Post hoc comparisons using Tukey's HSD revealed no significant pairwise differences.

Table 6. One-Way ANOVA Examining SCAT Baseline Symptom Severity by Type of Sport Contact (Collision, Contact, Non-contact)

Source	*SS*	*df*	*MS*	*F*	*p*	η^2
Between Groups	149.18	2	74.59	0.26	.775	.003
Within Groups	56323.40	198	284.46			
Total	56472.58	200				

Recovery Duration by Sport

Recovery durations varied significantly by sport contact level. A Kruskal-Wallis test revealed significant differences in median recovery times ($H(2) = 18.64$, $p < 0.001$, $\varepsilon^2 = 0.088$) (**Table 7**). Contact sports had the longest mean recovery durations ($M = 47.43$ days, $SD = 59.23$ days), nearly double those of collision ($M = 22.56$, $SD = 23.82$) and non-contact sports ($M = 23.11$, $SD = 30.84$) (**Table 8**).

Chi-square analyses of recovery categories also showed significant associations between sport type and recovery outcomes ($\chi^2(4) = 19.76$, $p < 0.001$). Collision sports had the highest proportion of persistent symptoms (25.8%), while non-contact sports had the highest rate of typical recovery (**Table 9**).

Table 7. Kruskal-Wallis Test of Recovery Duration by Contact Group

Contact Group	*Median* (days)	*M* (days)	*N*
Collision	24	60.7	97
Contact	34	93.7	68
Non-contact	14	31.0	36

Table 8. Recovery Durations by Sport Contact Category

Contact	*M*	*SD*	*Mdn*
Collision	60.74	76.81	24
Contact	93.74	111.95	34
Non-contact	30.97	40.67	14

Table 9. Distribution of Recovery Durations Across Contact Groups

Recovery Category	Collision (%)	Contact (%)	Non-Contact (%)
Normal (1-14 days)	(33.0)	(26.5)	(50.0)
Extended (15-28 days)	(20.6)	(19.1)	(19.4)
Persistent (>28 days)	(46.4)	(54.4)	(30.6)

Individual Sport Analysis

Table 10 presents the descriptive distribution of symptom duration categories by sport. Although variation was observed across sports, several sport-by-duration cells contained very small frequencies, including zero and one counts, particularly in sports with fewer reported cases. As such, these findings are presented descriptively and should be interpreted cautiously.

Table 10. Symptom Duration Categories by Sport ($N = 216$)

		Days					
Sport	*N*	0	1–7	8–14	15–21	22–28	>28
Football	43	20 (46.5)	8 (18.6)	6 (14.0)	2 (4.7)	2 (4.7)	5 (11.6)
Women's Basketball	10	2 (20.0)	0 (0.0)	2 (20.0)	0 (0.0)	0 (0.0)	6 (60.0)
Women's Rugby	18	4 (22.2)	5 (27.8)	3 (16.7)	1 (5.6)	2 (11.1)	3 (16.7)
Field Hockey	17	7 (41.2)	1 (5.9)	1 (5.9)	0 (0.0)	1 (5.9)	7 (41.2)
Men's Soccer	7	6 (85.7)	1 (14.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Women's Soccer	18	5 (27.8)	2 (11.1)	2 (11.1)	0 (0.0)	0 (0.0)	9 (50.0)
Men's Hockey	25	8 (32.0)	3 (12.0)	5 (20.0)	1 (4.0)	1 (4.0)	7 (28.0)
Men's Volleyball	14	8 (57.1)	0 (0.0)	1 (7.1)	0 (0.0)	1 (7.1)	4 (28.6)
Women's Volleyball	10	2 (20.0)	3 (30.0)	3 (30.0)	0 (0.0)	0 (0.0)	2 (20.0)
Track and Field	17	10 (58.8)	5 (29.4)	1 (5.9)	0 (0.0)	0 (0.0)	1 (5.9)
Wrestling	9	6 (66.7)	1 (11.1)	1 (11.1)	0 (0.0)	0 (0.0)	1 (11.1)
Men's Basketball	14	10 (71.4)	0 (0.0)	2 (14.3)	0 (0.0)	1 (7.1)	1 (7.1)
Women's Hockey	14	4 (28.6)	1 (7.1)	4 (28.6)	2 (14.3)	0 (0.0)	3 (21.4)
Total	216	92 (42.0)	30 (14.2)	31 (14.2)	6 (3.7)	8 (3.2)	49 (22.8)

Note. Values are presented as n (% within sport). Several sport-by-duration cells contained small frequencies, including zero and one counts, particularly in sports with fewer cases. Accordingly, this table should be interpreted descriptively, and sport-specific differences in symptom duration should be viewed cautiously.

A binary logistic regression was conducted to examine factors associated with persistent symptoms (>28 days). To improve model stability, sport type was aggregated into collision, contact, and non-contact categories. The final model, which included sex and aggregated sport type, was statistically significant ($\chi^2(3)= 12.77$, $p = .005$). Full parameter estimates appear in **Table 11**.

Contact sport participation demonstrated the largest effect size, with athletes in contact sports showing higher odds of persistent symptoms compared with those in non-contact sports (OR = 2.81; 95% CI, 0.94–8.39). Neither sex nor participation in collision sports was associated with increased odds of prolonged symptom duration.

Table 11. Logistic Regression Analysis of Factors Associated with Persistent Symptoms (>28 Days)

Predictor	*OR*	95% CI
Sex (Female)	1.52	0.69–3.39
Sport Type (Non-Contact)		
Collision	0.81	0.29–2.23
Contact	2.81	0.94–8.39

Notes. OR, odds ratios; CI, Confidence Intervals. Reference groups are indicated in parentheses.

Discussion

The purpose of this study was to examine differences in concussion history, baseline symptom presentation, sex, and sport participation and their association with recovery time among post-secondary student-athletes. The findings demonstrate that sex and sport context are significant determinants of both concussion baseline concussion symptom severity and total symptom count as well as past injury recovery duration, with female athletes displaying higher baseline concussion symptom severity scores, longer reported recovery durations, and greater odds of persistent post-concussion symptoms. Sport type also played an important role, with collision and contact sports associated with increased concussion history and longer recovery times. These results contribute novel insight into baseline symptom presentation and recovery patterns in post-secondary athletes.

Sex Differences in Baseline Concussion Symptom Reporting and Recovery

One of the most consistent findings in this study was the presence of sex differences in concussion baseline symptom reporting and recovery. Female athletes reported a significantly higher prevalence of previous concussion and endorsed higher baseline concussion symptom severity scores across all years of the study. These patterns mirror existing literature, which has repeatedly shown that females report greater baseline concussion symptom severity and a broader profile of somatic, cognitive, and emotional symptoms following concussion (Bazarian et al., 2010; Brown et al., 2015; Comeau et al., 2023; Sunderland et al., 2024; Wallace et al., 2017). Increased reporting may reflect physiological, hormonal, or biomechanical factors; however, behavioral and sociocultural contributors, such as greater health-seeking behaviors and symptom disclosure, could also play a role (Garrett et al., 2023; Kay et al., 2023; Wallace et al., 2017).

Recovery time was markedly different between sexes. Logistic regression further confirmed that sex was an independent predictor of persistent symptoms beyond 28 days. This finding aligns with meta-analytic evidence showing that female athletes exhibit prolonged recovery and higher odds of delayed symptom resolution (Cheng et al., 2019; Hou et al., 2023; Rice et al., 2018). Proposed explanations include sex differences in white matter microstructure, neck strength, oculomotor function, and hormonal fluctuations that may influence neurometabolic recovery trajectories (Bazarian et al., 2010; Garrett et al., 2023; Kamins et al., 2017). Regardless of mechanism, the present findings underscore the importance of sex-informed clinical management and reinforce recommendations for individualized RTP planning in female athletes (Patricios et al., 2023).

Sport Participation and Baseline Concussion Symptom Reporting

This study identifies clear differences in concussion history and recovery outcomes across sports. Collision sports, such as football and ice hockey, account for the largest proportion of athletes with previous concussions. This is consistent with longstanding epidemiological findings showing high concussion incidence in these sports (Giza & Hovda, 2001; Guskiewicz et al., 2003; Iverson et al., 2017; McPherson et al., 2019). Contact sports, including soccer, basketball, and field hockey, also contribute significantly to concussion baseline concussion symptom reporting. In contrast, non-contact sports represented the smallest proportion of athletes with previous concussion and demonstrated the lowest numbers of prolonged recovery.

While broad sport-type classifications were not associated with concussion symptom severity, descriptive variation was observed across individual sport. Women's soccer and field hockey athletes showed comparatively longer average recovery durations, whereas tennis and men's soccer showed the shorter durations. These sport-specific patterns should be interpreted cautiously given the small number of cases in several sports. As such, the findings are best understood as descriptive rather than definitive, but they suggest that potentially meaningful variation may be masked when sports are considered only within broad contact-based groupings. The comparatively longer recovery duration observed in women's soccer are broadly consistent with previous literature indicating elevated concussion risk in female soccer athletes in post-secondary sport settings (Bretzin et al., 2021; Cheng et al., 2019; Covassin et al., 2016), potentially related to heading exposure, cervical strength, and neurobiomechanical vulnerability (Garrett et al., 2023; Kay et al., 2023).

Collision sport participation though traditionally associated with higher concussion incidence did not independently predict prolonged recovery in the regression model. Instead,

specific sports (men's basketball and men's volleyball) emerged as significantly associated with SRC in male athletes. These findings may reflect under-recognized sport-specific risk patterns or behavioral factors related to reporting tendencies, training demands, and exposure patterns within these sports.

Predictors of Persistent Symptoms

Consistent with the study objective, logistic regression analyses identified sex and sport as significant predictors of prolonged recovery. Surprisingly, the number of previous concussions was not associated with recovery duration in the regression analysis, although athletes with RHOC did experience higher mean pre-season baseline concussion symptom severity. This contrast suggests that cumulative concussion exposure may influence level of pre-season symptom reporting but does not necessarily predict persistent symptoms. The literature on this association remains mixed, with some studies reporting cumulative effects (Montenigro et al., 2017; Zemek et al., 2017) and others showing minimal predictive value (Bruce & Echemendia, 2009). The present findings contribute to this debate and suggest that concussion history should remain a contextual but not determinative factor in recovery prognosis.

The strong effect of sex on recovery duration emphasizes the clinical relevance of individualized monitoring of female athletes following concussion. Given the higher odds of prolonged symptoms, CAT(C)s should consider more conservative progression criteria and ensure adequate monitoring of symptom fluctuations, vestibular and oculomotor function, and psychosocial stressors (Patricios et al., 2023).

Strengths and Limitations

This study possesses several notable strengths. It includes a large, multisport sample of post-secondary student-athletes assessed using standardized SCAT5/6 protocols and consistent clinical procedures across multiple years, enhancing methodological rigor and internal validity. The inclusion of collision, contact, and non-contact sports allowed for an examination of sport-specific profiles. Use of multiple analytic approaches including chi-square tests, ANOVA, non-parametric analyses, and logistic regression enabled a comprehensive assessment of both pre-season concussion symptom reporting and recovery duration from a prior concussion. The integration of subjective symptom reporting with structured clinical assessment tools further strengthens the interpretability of the findings.

Despite these strengths, several limitations merit consideration. First, concussion history, number of prior concussions, and recovery duration were self-reported, raising the possibility of recall bias and under or overreporting. Such self-report measures may also differ by sex and sport culture, potentially influencing group differences. Second, recovery duration data were incomplete for a subset of athletes; although this pattern is common in retrospective concussion research, the missing data may have reduced statistical power for survival analyses and could bias estimates if not missing at random. Third, the cross-sectional design restricts causal inference and prevents tracking of within-athlete changes across time or across concussions. Fourth, the use of multiple statistical comparisons across outcomes and subgroup analyses increases the possibility of Type I error, particularly for sport-specific findings, and therefore these results should be interpreted with appropriate caution.

Finally, because the sample was drawn from a single Canadian university with its own sport culture, training practices, and healthcare resources, generalizability to other post-

secondary or youth athletic settings may be limited. Future research incorporating multi-institutional samples, objective biomarkers, and prospective longitudinal follow-up would aid in addressing these limitations and build on the present findings.

Sandbagging in Baseline Testing

A recurring concern in baseline concussion assessment is the phenomenon of "sandbagging" which is the intentional underperformance by athletes during pre-season baseline testing to artificially lower their pre-injury reference values, with the goal of more easily meeting RTP clearance thresholds following a subsequent concussion (Erdal, 2012; Schatz et al., 2017). Sandbagging is a particular concern in cognitive and neurocognitive assessments where post-injury comparison to baseline is often used as a clearance criterion, and has been documented across professional, collegiate, and post-secondary settings.

While sandbagging is a legitimate concern for any baseline assessment program, it is important to clarify that the present study does not use baseline data for RTP clearance, and the findings reported here are not vulnerable to sandbagging in the way clinical clearance protocols are. The purpose of Study 1 was descriptive and population-level: to characterize patterns of pre-season symptom reporting, prior concussion history, and recovery duration across sex and sport categories in a large post-secondary cohort. Baseline scores were analyzed in aggregate rather than as individualized clearance thresholds, and no athlete in this study was cleared, restricted, or otherwise managed clinically on the basis of these data. The interpretive risk introduced by potential sandbagging is therefore limited to the direction and magnitude of group-level baseline symptom reporting. If athletes systematically underreported baseline symptoms, observed differences between sexes or sport types may be attenuated relative to true population values.

The motivation for sandbagging in clinical contexts reflects a broader misunderstanding of how baseline data are used. Athletes who underperform at baseline assume that a lower reference will provide easier clearance after concussion; however, contemporary concussion management is rarely guided by a single baseline-to-post-injury comparison and increasingly emphasizes multimodal symptom resolution, clinical examination, and graduated RTP progression rather than baseline-referenced thresholds alone (Patricios et al., 2023). Educating athletes about the actual role of baseline data including the role of population-level baselines in research such as the present study is an important component of reducing intentional underperformance. Future iterations of post-secondary baseline protocols, including VADAR, may benefit from explicit pre-test athlete education regarding the non-clinical, research-oriented use of baseline assessments to mitigate sandbagging risk and to strengthen the interpretive value of baseline data at both individual and population levels.

Conclusion

This study demonstrates that sex and sport participation are significant factors associated with pre-season baseline concussion symptom reporting and recovery duration in post-secondary student-athletes, whereas concussion history alone was not associated with prolonged recovery. Female athletes and athletes participating in several high-risk sports reported higher levels of pre-season baseline concussion symptoms prior to injury and longer recovery times, underscoring the need for sex- and sport-specific approaches to concussion assessment and management. These findings highlight meaningful variability in concussion outcomes across different athlete groups and reinforce the importance of considering both sex and sport context when interpreting baseline symptom presentation and expected recovery trajectories.

Chapter 3. Concussion Trends Among Ontario Colleges Athletic Association Post-Secondary Student-Athletes

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Abstract

Background: Sport-related concussion (SRC) is a major health concern in post-secondary athletics. Despite growing research and policy efforts across Canadian universities, athletes competing within the Ontario Colleges Athletic Association (OCAA) remain underrepresented in exposure adjusted epidemiological literature. The absence of centralized surveillance and standardized exposure metrics has limited accurate estimation of sport-specific concussion risk within this population.

Objectives: To examine sex-based, sport-specific, and contextual patterns of SRC among post-secondary student-athletes in the OCAA from 2018 to 2023, and to estimate competition-related concussion incidence using athlete-exposure (AE) data where available.

Methods: A retrospective, surveillance study was conducted using 780 concussion cases reported by Certified Athletic Therapists (CAT(C)) across 23 OCAA institutions. Descriptive analyses examined sex, sport, injury mechanism, activity context, symptom duration, and academic accommodations. For a subset of collision and contact sports, competition related AE was estimated using team level game counts and roster sizes, allowing calculation of incidence rates (IRs) per 1,000 AE with 95% confidence intervals. Group differences were assessed using chi-square tests, independent t-tests, and ANOVA.

Results: Across all reported SRCs, female athletes accounted for 58.2% of cases. Most concussions occurred during games (64.0%), with direct contact as the most common mechanism (45.9%). Mean symptom duration was 17.2 days (SD = 25.7), with 21.8% exceeding 21 days and 14.2% exceeding 28 days. Academic accommodations were provided to 44% of athletes with available data. Exposure adjusted analyses included 453 competitions related SRCs across

54,593 AE. Men's Rugby demonstrated the highest incidence (36.4 per 1,000 AE; 95% CI: 29.2 - 44.9), followed by women's rugby sevens (15.0 per 1,000 AE; 95% CI: 10.7–20.4), women's soccer (11.4 per 1,000 AE; 95% CI: 9.3–13.9), and women's basketball (9.6 per 1,000 AE; 95% CI: 7.5–12.2). Several sports with high raw concussion counts demonstrated more moderate incidence once exposure was considered.

Conclusion: SRCs are common among OCAA post-secondary student-athletes and are associated with substantial symptom duration and academic disruption. Exposure adjusted analyses reveal marked variation in sport-specific concussion risk that is not apparent from case counts alone, particularly among female-dominated sports. These findings underscore the necessity of incorporating AE into Canadian college concussion surveillance and provide a critical foundation for evidence informed injury prevention and return-to-learn (RTL) policy development.

Introduction

Sport-related concussion (SRC) remains a critical public health concern in post-secondary athletics, particularly within settings where medical resources, data infrastructure, and surveillance systems are limited. Defined by the Concussion in Sport Group (CISG) as a traumatic brain injury induced by biomechanical forces, SRC typically results in rapid-onset neurological impairment that may resolve over time but can vary widely in recovery duration (McCrory et al., 2017). Despite its prevalence, the monitoring and management of concussion in Canadian post-secondary sport remain inconsistent. U SPORTS institutions have increasingly adopted structured concussion education and clinical protocols, yet Canadian colleges, particularly those under the Ontario Colleges Athletic Association (OCAA), lack comparable systems capable of generating reliable epidemiological data (Giza & Hovda, 2001; Langlois et al., 2006).

This absence of centralized surveillance creates substantial knowledge gaps. Without standardized tracking, it is difficult to assess sport-specific concussion risk, identify sex differences, monitor outcomes, or evaluate prevention strategies. Although the National Collegiate Athletic Association Injury Surveillance Program (NCAA-ISP) provides a robust model for longitudinal injury surveillance in the United States (Chandran, Morris, et al., 2021; Chandran, Boltz, et al., 2021; Iverson et al., 2017; Dick et al., 2007), no equivalent infrastructure exists for Canadian universities or colleges. As a result, athletes competing in Ontario college sport remain largely unstudied, despite representing a substantial proportion of Canada's post-secondary athletic population.

SRC in post-secondary settings pose challenges that extend beyond physical recovery. Concussion can disrupt academic performance, alter course progression, and increase stress

related to balancing academic and athletic obligations (Hossler et al., 2014; Halstead et al., 2013; Kontos, Elbin, et al., 2012; Kontos, Covassin, et al., 2012; McAvoy, 2012; Iverson & Lange, 2003). Return-to-learn (RTL) processes, although increasingly recognized in pediatric and secondary school settings, are inconsistently implemented in post-secondary sport. OCAA athletes often complete shorter two- or three-year academic programs, leaving less flexibility for missed coursework or delayed progression (Bovard, 2008; McAvoy et al., 2020; Meier et al., 2015; Scopaz & Hatzenbuehler, 2013). RTL disruptions in this population may therefore carry unique educational and psychosocial consequences.

Sex-based differences further complicate concussion epidemiology. Female athletes consistently demonstrate higher concussion rates, more severe symptom profiles, and longer recovery durations in sex-comparable sports such as soccer, basketball, and ice hockey (Bretzin et al., 2021; Covassin et al., 2016; Dick, 2009; Broshek et al., 2005; Koerte et al., 2020). These outcomes likely reflect a complex interplay of biomechanical susceptibility, hormonal influences, and sociocultural factors affecting symptom disclosure and care-seeking behavior.(Kerr, Register-Mihalik, et al., 2014; Kroshus et al., 2015; Wallace et al., 2017). Within the OCAA, where medical staffing, baseline testing, and sport-specific training resources vary substantially across institutions, such sex differences warrant close examination (Crain et al., 2016; Frémont et al., 2015; Halstead et al., 2013; Hossler et al., 2014; Iverson & Lange, 2003; Kerr et al., 2018; Kontos, Covassin, et al., 2012; Kontos, Elbin, et al., 2012; McAvoy, 2012).

The purpose of this study is to provide a multi-year descriptive analysis of sport-related concussions reported in the Ontario Colleges Athletic Association between 2018 and 2023. Specifically, this study aims to examine sex-based differences, sport-specific distributions, mechanisms of injury, symptom duration, recovery patterns, and the academic impact of SRCs

among post-secondary athletes. By doing so, it addresses a critical gap in Canadian post-secondary concussion research and provides foundational data to inform future surveillance, prevention strategies, and RTL protocols within the OCAA.

Methods

Study Design

This study uses a retrospective surveillance design to examine SRCs reported among post-secondary student-athletes in the OCAA across four academic seasons: 2018–2019, 2019–2020, 2021–2022, and 2022–2023. The 2020–2021 season was excluded due to the suspension of intercollegiate sport during the COVID-19 pandemic, consistent with widespread disruptions to athletic participation and injury surveillance during this period (Wiltshire et al., 2022).

The primary objectives were to describe concussion injury characteristics, symptom duration recovery patterns, and academic impact, and where exposure data were available, to estimate competition-related concussion incidence using AE. Although the retrospective nature of the data precludes causal inference, this design is appropriate for characterizing injury patterns and estimating IRs using aggregated exposure denominators in the absence of prospective surveillance infrastructure. Additionally, because the datasets differed in structure and unit of analysis (athlete-level vs injury-level), pooled statistical analysis was not feasible. Therefore, cross-study comparison relied on conceptually comparable variables across the two datasets and conducting descriptive comparative analyses.

Data were obtained from secondary, operational records collected by Certified Athletic Therapists CAT(C) at OCAA institutions for internal monitoring purposes and later aggregated for research analysis. All data were de-identified prior to analysis. Ethics approval was obtained

from York University's Human Participants Review Committee (Certificate #: e2024-231), and the study complies with national guidelines for secondary use of non-identifiable health data (Government of Canada, 2019; Statistics Canada, 2023).

Participants

The sample contains 780 de-identified post-secondary student-athlete SRC cases reported between September 2018 and April 2023 from 23 of 26 OCAA member institutions, across 4 provincial regions (see Table 12). Concussions were documented by CAT(C)'s and allied medical personnel based on clinical evaluation and athlete self-report. Each case met the eligibility criteria of a concussion sustained during participation in an OCAA-sanctioned sport, as diagnosed or documented by a designated health professional. No exclusion criteria were applied.

Inconsistent measurement of athlete-level identifiers, age, and cumulative exposure meant that, within the reporting tool, the unit of analysis was the injury event rather than the individual athlete. As a result, repeat concussions could not be identified. Athlete sex was inferred from post-secondary team designation (e.g., men's or women's teams), resulting in binary classification and limiting analysis by gender identity. However, the athlete population generally mirrors other Canadian post-secondary cohorts and sex, sport, injury mechanism, injury context (e.g., practice vs. competition), and academic impacts (e.g., accommodations, course load changes) were recorded consistently.

Data were submitted annually via a standardized form to a centralized repository maintained by the OCAA Athletic Therapist Working Group. While the reporting process was relatively stable over the study period, data collection around academic disruption (e.g.,

accommodations, modified course loads) became more robust post-pandemic, reflecting a growing institutional awareness of the cognitive and educational consequences of SRC (Collie et al., 2006; Echemendia et al., 2017; McCrory et al., 2017; Rice et al., 2018).

Table 12. Concussion Distribution by Ontario Region

Region	Total Number of Institutions	Total Number of Concussion (*n*)
West	7	239
North	7	59
South	6	237
East	6	245

Note. Distribution by geographical location of reported concussions by Ontario College Athletics Association (OCAA) between 2018 and 2023. Region is according to OCAA conference reporting.

The four OCAA regions (West, North, South, East) differ in the number of member institutions, the range of varsity sports offered, and total varsity enrolment, which contributes meaningfully to the observed regional variation in concussion case counts. The West and North regions contain the largest number of institutions and field a greater range of sanctioned sports, including high-incidence sports such as men's rugby, women's rugby sevens, women's soccer, and women's basketball, which collectively account for the majority of reported SRCs in the dataset. The South region similarly contains a moderate number of institutions with broad sport offerings, while the North region has similar institutions and a more limited sport roster, particularly with respect to higher-incidence team sports. The lower case count in the North region (n = 59) therefore likely reflects a smaller exposure base that is, fewer athletes participating in fewer high-risk sports rather than a lower per-exposure concussion risk among Northern athletes. Because athlete-exposure could only be estimated at the sport and roster level, exposure-adjusted incidence could not be calculated by region; regional case counts should

therefore be interpreted as reflecting institutional and sport-distribution differences rather than relative regional safety.

Measures

Athlete and Sport Characteristics

Athlete sex was not directly recorded and was inferred from post-secondary team designation (e.g., men's basketball). This approach imposed binary categorization and assumed institutional accuracy but did not lead to case exclusion. Sport was entered as free text and later coded into collision, contact, and non-contact categories. Institutional identifiers were retained but are not reported due to privacy constraints. Injury timing was recorded by academic year and seasonal phase (pre-season, in-season, post-season, off-season), based on institutional definitions aligned with sanctioned competition dates.

Injury Characteristics

Injury variables included year of injury, activity context, mechanism of injury (MOI), and recovery-related fields. Year was recorded by academic cycle (e.g., 2021–2022) to permit pre- and post-pandemic comparison. Activity context included game, practice, strength training/cardio, or non-sport-related, with only one option per case. MOI was recorded from a fixed menu (direct head contact, body contact, ground, equipment, other), limiting documentation of multifactorial events. Symptom duration reflected the number of days from injury to full symptom resolution based on therapist judgment and athlete report; no standardized method was enforced across institutions. Extreme values were retained but interpreted cautiously.

Recovery time categories were derived post hoc (1–7, 8–14, 15–21, 22–28, >28 days) consistent with clinical recovery benchmarks. These categories reflect five clinically meaningful intervals: 1 to 7 days (rapid recovery), 8 to 14 days (typical recovery), 15 to 21 days (delayed recovery), 22 to 28 days (prolonged recovery), and more than 28 days (extended recovery; Leddy, et al., 2017; Nelson et al., 1984; Patricios et al., 2023). Persistent recovery was defined as symptom duration exceeding 28 days following the most recent concussion, consistent with contemporary concussion consensus literature distinguishing typical recovery trajectories from prolonged symptom presentation in adult populations (Leddy et al., 2023 Nelson et al., 1984; Patricios et al., 2023). These intervals align with consensus recommendations for SRC recovery trajectories in adolescent and young adult athletes (Halstead et al., 2013; Iverson et al., 2017).

Academic Impact

Academic impact fields shifted after the pandemic. Between 2018 and 2020, disruptions were recorded as games missed, practices missed, and days missed from school, measures based on athlete self-report without standardized definitions. Following the return to play in 2021, academic variables were revised to include days symptomatic, academic accommodations (yes/no), and changes in course load (none, decreased, or loss of semester). Only formally documented accommodations were recorded; informal adjustments were not captured. These additions aligned with emerging RTL models emphasizing academic consequences of concussion (McAvoy et al., 2020).

Athlete-exposure and Incidence Calculation

Competition-related athlete-exposure (AE) was estimated for select collision and contact sports using team-level game counts and roster sizes (Kerr, Dompier, et al., 2014). One AE was

defined as one athlete participating in one sanctioned game, consistent with standard injury surveillance methodology (Hootman et al., 2007).

For each sport and season, total AE was calculated as:

$$AE = \text{Total Number of Games} \times \text{Roster Size}$$

Roster sizes were assumed to remain constant within each season based on OCAA regulations and publicly available team information. Exposure estimates were limited to competition only; practice exposures were unavailable and therefore excluded (Chandran, Morris, et al., 2021). As a result, IRs reflect only game-related concussion risk and do not represent total sport exposure.

Sport-specific concussion IRs were calculated as the number of game-related SRCs per 1,000 AE. Ninety-five percent confidence intervals (95% CIs) were calculated assuming a Poisson distribution. Incidence analyses were restricted to sports for which reliable game and roster data were available.

Statistical Analyses

Analyses were conducted using IBM SPSS Version 29.0.1 and Excel 365. Significance was set at $p < .05$. Effect sizes (e.g., η^2, Cramer's V) were reported where applicable. Descriptive statistics summarized all categorical and continuous variables. Chi-square tests evaluated associations between sex and sport, MOI, and activity context. Independent-samples *t*-tests compared mean symptom durations by sex. ANOVA examined symptom duration across sport contact categories with Tukey's HSD used for post hoc comparisons. All tests were two-tailed. Primary analyses used pooled data across all four years to maximize power, with stratified seasonal summaries examined separately.

Methodological Considerations

While the use of dropdown menus for data entry helped promote consistency across institutions, this structure also constrained the depth of information that could be captured. For example, CAT(C)'s were restricted to selecting only a single mechanism of injury per case, which limited the ability to represent multi-factorial or ambiguous injury events. Additionally, no formal training was provided to therapists on how to interpret or complete the standardized forms, increasing the potential for inconsistent reporting practices and variable data quality across member institutions. Certain key classifications (i.e., athlete sex, recovery bracket, and sport contact level) were not present in the raw dataset and were subsequently assigned by the research team during the data cleaning phase. Despite these limitations, the dataset was complete for all variables that remained in use during their respective data collection periods. The 2020–2021 season was excluded in its entirety due to the suspension of intercollegiate sport activities during the COVID-19 pandemic

Results

Athlete and Sport Characteristics

A total of 780 sport-related concussions (SRCs) were reported by 23 of 26 OCAA institutions between September 2018 and April 2023, excluding the 2020–2021 season. Annual case counts peaked in 2019–2020 and declined in 2021–2022, with totals in 2022–2023 returning to near pre-pandemic levels (**Figure 3**).

Female athletes accounted for 58.2% (n = 454) of reported concussions, while male athletes accounted for 41.8% (n = 326) (**Table 13**). Across all cases, concussions were most

frequently reported in contact sports (42.6%), followed by collision (27.2%) and limited/non-contact sports (30.3%).

Table 13. Descriptive Breakdown of Concussion Cases by Sex, Sport Type, and Injury Context Among OCAA Post-Secondary Student-Athletes (2018–2023)

Variable	Category	*n*	%
Sex			
	Male	326	41.8
	Female	454	58.2
Sport Type			
	Collision	212	27.2
	Contact	332	42.6
	Limited / Non-contact	236	30.3
Injury Context			
	Game	499	64.0
	Practice	196	25.1
	Other	85	10.9

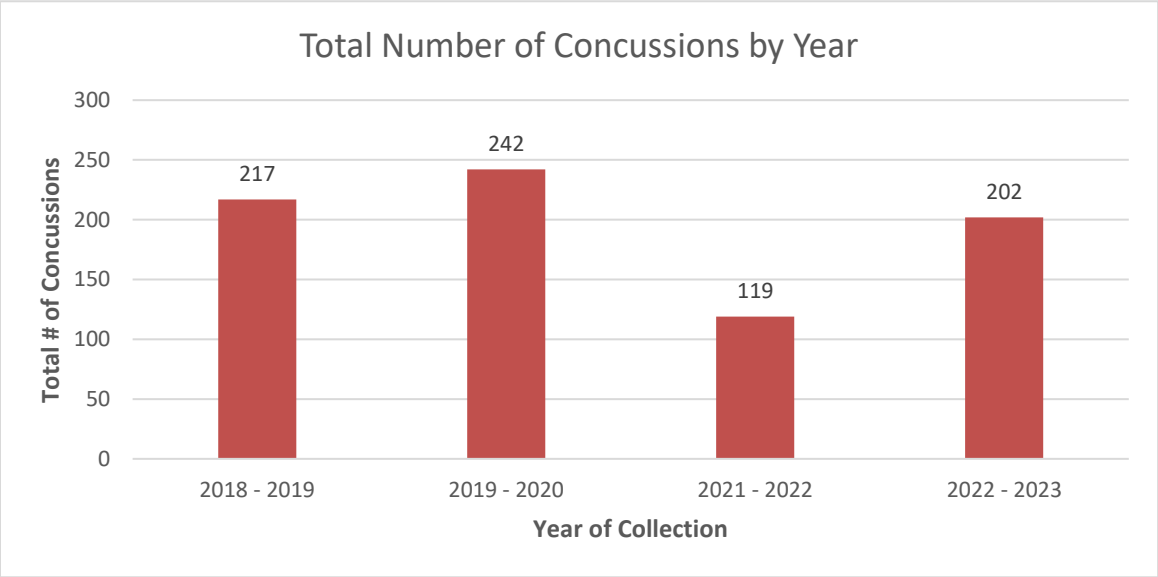


Figure 3. Total Reported OCAA Varsity Athletes Concussions by Year (2018–2023)

Sport-Specific Distribution of Concussion Cases

Raw concussion counts varied substantially by sport (**Table 14**). Women's soccer (15.5%), women's basketball (15.0%), men's rugby (14.0%), and women's volleyball (12.8%) accounted for over 57% of all reported SRCs. These sports consistently ranked among the highest contributors across study years.

Consistent with the literature, men's rugby, a high-collision sport, ranked among the highest in concussion reports each year, particularly in 2018-2019 and 2019-2020. In contrast, elevated concussion case counts in women's basketball and women's volleyball (sports traditionally classified as non-collision) highlight that concussions are not confined to collision sports alone.

However, because sports differ markedly in team size and number of games, these distributions cannot be interpreted as indicators of relative concussion risk without exposure adjustment.

Table 14. Reported Concussions by Sport, Contact Level, and Year of Collection (2018–2023) in the Ontario Colleges Athletic Association, $N = 780$

Type of Sport	Sport	Year of collection				Total (%)
		2018 - 2019	2019 - 2020	2021 - 2022	2022 - 2023	
Collision Sport	Men's Rugby	38	35	13	23	109 (67.3)
	Women's Rugby 7's	10	22	9	12	53 (32.7)
	Total	48	57	22	35	162 (20.8)
Contact Sport	Men's Basketball	20	28	11	19	78 (18.8)
	Women's Basketball	30	34	21	32	117 (28.2)
	Men's Soccer	19	17	10	13	59 (14.2)
	Women's Soccer	32	35	19	35	121 (29.2)
	Women's Indoor Soccer	9	12	5	5	31(7.5)
	Total	113	129	68	105	415(53.2)
Non-Contact Sport	Men's Volleyball	22	18	6	14	60 (29.6)
	Women's Volleyball	22	27	16	35	100 (49.3)
	Total	56	56	29	62	203 (26.0)

Athlete-exposure (AE) Summary

Competition-related AE was estimated for collision and contact sports using team-level game counts and roster sizes, yielding a total of 54,593 AE across eligible sports and seasons. A total of 453 game-related SRCs were included in exposure-adjusted analyses.

Sport-Specific Incidence Rates

Exposure-adjusted concussion incidence varied widely by sport (**Table 15**). Men's rugby demonstrated the highest incidence at 36.4 per 1,000 AE (95% CI: 29.2–44.9), substantially exceeding all other sports. Women's rugby sevens showed the second-highest incidence at 15.0 per 1,000 AE (95% CI: 10.7–20.4). Among contact sports, women's soccer exhibited an elevated incidence (11.4 per 1,000 AE; 95% CI: 9.3–13.9), more than double that of men's soccer (4.8 per

1,000 AE; 95% CI: 3.4–6.6). Women's basketball demonstrated a higher incidence (9.6 per 1,000 AE; 95% CI: 7.5–12.2) than men's basketball (4.9 per 1,000 AE; 95% CI: 3.6–6.6). Volleyball exhibited comparatively lower IRs, particularly among men (2.9 per 1,000 AE), despite high raw concussion counts.

Table 15. Competition-Related Concussion Incidence by Sport in OCAA Post-Secondary Athletics (2018 – 2023)

Sport	Seasons	*n* (Games)	Roster Size	Total AE	RHOC	AE (95% CI)
Men's Basketball	2018–2023	765	12	9,180	45	4.9 (3.6–6.6)
Women's Basketball	2018–2023	596	12	7,152	69	9.6 (7.5–12.2)
Men's Rugby	2018–2023	105	23	2,415	88	36.4 (29.2–44.9)
Women's Rugby 7's	2018–2023	222	12	2,664	40	15.0 (10.7–20.4)
Men's Soccer	2018–2023	366	22	8,052	39	4.8 (3.4–6.6)
Women's Soccer	2018–2023	395	22	8,690	99	11.4 (9.3–13.9)
Men's Volleyball	2018–2023	685	12	8,220	24	2.9 (1.9–4.3)
Women's Volleyball	2018–2023	685	12	8,220	49	6.0 (4.4–7.9)

Note. AE, athlete-exposure: defined as one athlete participating in one sanctioned game (Incidence per 1,000). AE estimates were calculated using team-level game counts and assumed roster sizes. Incidence rates reflect competition-related concussions only; CI, Confidence interval: calculated assuming a Poisson distribution; RHOC, Reported history of concussion.

Injury Characteristics

Activity context

The majority of concussions occurred during competitive games (64.0%), while a quarter occurred during practices (25.1%). A further 10.5% were sustained during non-sport-related activities (e.g., recreational sport, falls outside of team activities), and 0.4% were attributed to strength training or cardio (**Table 16**).

A chi-square test revealed a statistically significant association between athlete sex and activity context, $p = .015$. Female athletes accounted for the majority of concussions during both

games (n = 291) and practices (n = 102), and disproportionately more injuries in non-sport-related contexts (n = 58) compared to male athletes (n = 24).

No exposure-adjusted analyses were conducted for practice or non-sport-related injuries due to the absence of practice exposure data.

Table 16. Frequency of Concussions by Activity Context and Sex (N = 780)

Activity Context	Male (%)	Female (%)	Total (%)
Game	208 (26.7)	291(37.3)	499 (64.0)
Practice	94 (12.1)	102 (13.1)	196 (25.1)
Non-sport related	24 (3.1)	58 (7.4)	82 (10.5)
Total	326 (41.8)	454 (58.2)	780 (100)

Note. Chi-Square $\chi^2(3, N = 780) = 10.51$, $p = .015$

Mechanism of Injury (MOI)

Mechanism-of-injury (MOI) data were available for 321 cases (41.2%) (**Table 17**). Direct head contact was the most frequently reported mechanism (49.5%), followed by equipment-related impacts (23.4%), ground contact (13.1%), and body contact (10.6%).

A significant association was observed between sex and MOI, $p = .009$. Equipment-related mechanisms were more frequently reported among female athletes, while direct head contact was common across both sexes.

Table 17. Distribution of Reported Mechanisms of Injury by Sex (n = 321)

Mechanism of Injury	Male (%)	Female (%)	Total Valid Cases (%)
Body Contact	10 (3.1)	24 (7.5)	34 (10.6)
Direct Head Contact	74 (23.1)	85 (7.5)	159 (49.5)
Equipment	18 (5.6)	57 (17.8)	75 (23.4)
Ground	13 (4.0)	29 (9.0)	42 (13.1)
Total	120 (37.4)	201 (62.6)	321 (41.2)

Note. A significant association was observed between sex and mechanism of injury, $\chi^2(4, N = 321) = 13.41$, $p = .009$; Cramer's $V = 0.20$

Symptom Duration

Symptom duration data were available for 309 cases. Mean symptom duration was 17.2 days (*SD* = 25.7) and did not differ significantly by sex (**Table 18** and **19**). To reduce small-cell disclosure risk, descriptive symptom duration values were grouped into broader sport categories in **Table 20**. Although mean symptom duration varied across sports, the one-way ANOVA conducted on the original sport categories indicated that these differences were not statistically significant, $F(12, 296) = 1.12$, $p = .347$, $\eta^2 = .043$ (**Table 21**).

When categorized into recovery brackets, 65.7% of athletes recovered within 14 days, while 18.8% experienced symptoms beyond 21 days and 12.0% exceeded 28 days (**Figure 4**). Prolonged recovery was observed across multiple sports rather than concentrated within a single discipline (**Table 21**).

Table 18. Mean Symptom Duration by Sex (*n* = 309)

Sex	Days symptomatic (*n*)	Minimum	Maximum	*M*	*SD*
Male	119	0	220	18.9	33.7
Female	190	0	150	16.2	19.1
Total	309	-	-	17.2	25.7

Table 19. Independent Samples *t*-Test Symptom Duration by Sex (*n* = 309)

Variable	Group	*n*	*M*	*SD*	*MD*	95% CI for Diff	95% CI
Days Symptomatic	Male	119	18.89	33.68			
	Female	190	16.16	19.14	2.73	-3.95 - 9.42	-0.123 - 0.335

Note. $p < 0.05$; CI, confidence interval; SD, standard deviation

Table 20. Mean Symptom Duration by Sport (*n* = 309)

Sport Group	Days symptomatic (*n*)	Minimum	Maximum	*M*	*SD*
Basketball	80	0.0	220.0	21.7	38.5
Rugby	54	1.0	94.0	15.9	23.5
Soccer/Indoor Soccer	89	0.0	150.0	13.6	20.2
Volleyball	68	1.0	77.0	17.0	15.0
Other sports	18	4.0	45.0	20.0	14.0
Total	309	0.0	220.0	17.2	25.7

Note. Sport categories were collapsed to reduce small-cell disclosure risk in descriptive reporting. Other sports include men's baseball, women's softball, and men's badminton.

Table 21. One-way ANOVA Symptoms by Sport (*n* = 308)

Source	*df*	*SS*	*MS*	*F*	*p*	η^2	95% CI
Between Groups	12	8807.56	733.96	1.115	.347	.043	.000 - .055
Within Groups	296	194857.77	658.30				
Total	308	203665.33					

Note. The ANOVA was conducted using the original sport categories to preserve analytic specificity. Descriptive reporting was collapsed in Table 20 to reduce small-cell disclosure risk. $p < 0.05$

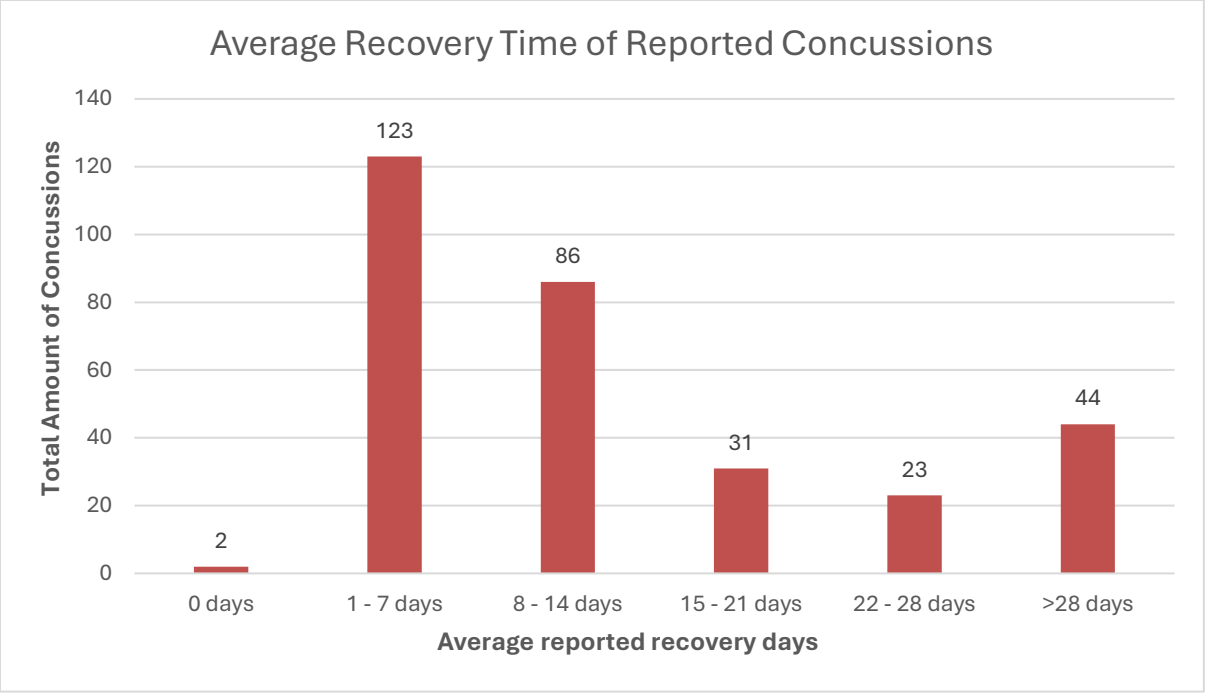


Figure 4. Distribution of Symptom Duration by Recovery Bracket (*n* = 309)

Recovery Bracket Classification

To summarize the distribution of symptom duration, recovery times were categorized into standardized brackets. As shown in **Figure 4**, the largest proportion of recoveries fell within the 1–7 day window (34.3%), followed closely by the 8–14 day group (31.4%). These findings align with existing research suggesting that most SRCs resolve within two weeks for the majority of athletes (van Mechelen, 1997). However, 15.5% of cases extended into the 15–21 day range, and 21.7% reported prolonged recovery beyond 21 days.

Table 22 presents symptom duration in collapsed recovery categories by sport group. Across the sample (*n* = 309), 125 athletes (40.5%) reported symptom durations of 0–7 days, 117 (37.9%) reported durations of 8–21 days, and 67 (21.7%) reported symptoms lasting more than 21 days. Soccer/indoor soccer contributed the largest number of cases overall (*n* = 89), followed by basketball (*n* = 80) and volleyball (*n* = 68). The largest number of cases in the >21 day

category was observed in volleyball (n = 20), followed by soccer/indoor soccer (n = 16) and basketball (n = 15). Within this longest-duration category, 44 athletes (14.2%) experienced symptoms lasting more than 28 days, a threshold commonly used to identify persistent post-concussion symptoms in contemporary concussion literature (Bretzin et al., 2021; Echemendia et al., 2023; Kamins et al., 2017; McAllister et al., 2023).

Table 22. Distribution of Athletes by Collapsed Symptom Duration Recovery Category, by Sport Group (n = 309)

Sport	0-7 days	8-21 days	>21 days	Total
Basketball	31	34	15	80
Rugby	28	17	9	54
Soccer/Indoor Soccer	42	31	16	89
Volleyball	19	29	20	68
Other sports	5	6	7	18
Total	125	117	67	309

Note. Recovery categories were collapsed to reduce small-cell disclosure risk. The 0–7 day category includes athletes reporting 0 days and 1–7 days of symptoms; the 8–21 day category includes athletes reporting 8–14 days and 15–21 days of symptoms; and the >21 day category includes athletes reporting 22–28 days and >28 days of symptoms. Other sports include men's baseball, women's softball, and men's badminton. Although recovery is presented in collapsed categories, 44 athletes (14.2%) were classified in the >28 day bracket.

Academic Accommodations

To reduce small-cell disclosure risk, academic accommodation outcomes were grouped by broader sport category in **Table 23**. Among the 318 cases with available academic data, 140 athletes (44.0%) required at least one documented academic accommodation following concussion. Although the Other Sports category demonstrated the highest accommodation proportion (65%), this finding was based on only 13 accommodated athletes and should be interpreted cautiously given the small number of concussion cases. This was followed by

volleyball with (49.3%), basketball (43.4%), rugby (40.7%), and soccer/indoor soccer (37.8%). However, these descriptive differences likely reflect variation in the number of concussion cases across sport groups rather than meaningful differences in exposure-adjusted concussion risk.

Despite these descriptive differences across sport groups, academic status did not differ significantly by sex, $p = .968$. Similarly, no sex-based difference was observed in the academic accommodation indicator, $t(316) = 0.039$, $p = .937$, $d = 0.005$ (**Table 24**).

Table 23. Academic Accommodation Status by Sport Group ($n = 318$)

Sport	Academic accommodations		Total (*M, SD)*
	Yes	*No*	
Basketball	36	47	83 (0.43, 0.50)
Rugby	22	32	54 (0.41, 0.50)
Soccer/Indoor Soccer	34	56	90 (0.38, 0.49)
Volleyball	35	36	71 (0.49, 0.50)
Other sports*	13	7	20 (0.65, 0.49
Total	140	178	318 (0.44, 0.50)

Note. M, Mean; *SD*, Standard Deviation; Sport categories were collapsed to reduce small-cell disclosure risk. Academic accommodation status was coded as a binary variable (1 = yes, 0 = no). Mean values represent the proportion of athletes within each sport group who received at least one documented academic accommodation. *Other sports category includes men's baseball, women's softball, and men's badminton.

Table 24. Independent Samples t-Test Comparing Number of Academic Accommodations by Sex ($n = 318$)

Variable	Sex	*n*	*M*	*SD*	*p*	*d*
Academic Accommodations	Male	120	0.44	0.49		
	Female	198	0.43	0.49	.937	0.005

Note. Academic accommodation status was coded as a binary variable (1 = yes, 0 = no). Higher mean values indicate a greater proportion of athletes who received at least one documented academic accommodation. $p < 0.05$

Discussion

Overview of Findings

This study provides the first multi-year, exposure-adjusted examination of SRC among OCAA post-secondary student-athletes. By integrating both raw concussion counts and competition-based AE estimates, the findings show that concussion case counts and concussion risk are not interchangeable constructs. While descriptive case counts identified sports with substantial concussion volume, exposure-adjusted IRs revealed meaningful sport and sex specific differences in per exposure risk that are not apparent from counts alone (Bovard, 2008; McAvoy, 2012; Meier et al., 2015). The inclusion of AE fundamentally alters interpretation of SRC patterns within Canadian college sport. Several sports with high absolute numbers of concussions demonstrated moderate incidence once exposure was considered, whereas others, most notably men's rugby and women's soccer, exhibited persistently elevated risk after adjustment. These findings underscore the importance of incorporating exposure metrics into concussion surveillance systems and caution against relying solely on proportional distributions when prioritizing injury prevention efforts (Cheng et al., 2019; Meehan et al., 2012).

Sex Differences and Sport Specific Risk After Exposure Adjustment

Female athletes accounted for a greater proportion of reported SRCs across the full dataset, a pattern consistent with previous post-secondary and high school surveillance literature documenting higher concussion reporting among females in sex-comparable sports such as soccer and basketball (Bretzin et al., 2021; Covassin et al., 2016; Dick, 2009). However, exposure adjusted analyses clarify that sex differences are not uniform across sports.

Women's soccer and women's basketball demonstrated higher IRs than their male counterparts, aligning with findings from NCAA Injury Surveillance Program and CARE Consortium studies reporting elevated concussion incidence among female athletes even after accounting for participation exposure (Chandran et al., 2021; Master et al., 2021; Zuckerman et al., 2015). Proposed explanations include biomechanical differences, neck strength, hormonal influences, and sex-based differences in symptom recognition and reporting behaviors (Broshek et al., 2005; Koerte et al., 2020; Wallace et al., 2017).

In contrast, women's volleyball despite contributing a substantial number of concussion cases demonstrated comparatively moderate incidence once AE was considered. This distinction highlights the risk of over-interpreting raw counts in sports with large team sizes or extensive competition schedules and reinforces the importance of exposure adjustment when distinguishing overall case volume from underlying concussion risk (Kerr et al., 2018; van Mechelen, 1997).

Men's rugby emerged as the highest-risk sport by a considerable margin, with IRs greater than those of all other sports. This finding is consistent with prior international and post-secondary research identifying rugby as a high-risk collision sport due to frequent high magnitude impacts, tackling demands, and limited protective equipment (Harmon et al., 2013; Hootman et al., 2007; Zuckerman et al., 2015). Importantly, the magnitude of risk persisted after exposure adjustment, supporting the conclusion that elevated incidence reflects intrinsic sport risk rather than surveillance artifact.

Men's soccer, basketball, and volleyball contributed to the overall concussion case count but did not approach the concentration observed in the four leading sports. At the lower end, sports such as curling, badminton, golf, and cross-country accounted for fewer than five cases across all years and were suppressed or aggregated to maintain anonymity under PHIPA.

These findings reinforce that “non-contact” sport classification does not eliminate concussion risk, particularly in female-dominated settings. Women’s volleyball may benefit from targeted prevention strategies and enhanced sideline recognition practices. OCAA-wide education efforts could highlight these high concussion case counts, especially where risk may be underestimated by coaches or administrators.

Injury Context and Mechanism in Relation to Exposure

Consistent with prior surveillance studies, the majority of SRCs in this cohort occurred during competitive games rather than practices (Chandran et al., 2021; Kerr et al., 2018; Zuckerman et al., 2015). Competitive play is characterized by increased speed, intensity, and unpredictability, all of which contribute to elevated concussion risk relative to training environments (Hootman et al., 2007; Wasserman et al., 2016).

The absence of practice exposure data were limited exposure-adjusted analyses to competition-related injuries. This likely led to an underestimation of overall concussion risk, particularly in sports with high practice-to-game exposure ratios. Nevertheless, the predominance of game-related SRCs supports the use of competition based AE as a pragmatic and defensible first step in Canadian college concussion surveillance (Kerr et al., 2018; van Mechelen, 1997). While practice-related concussions are less common, they remain nontrivial, raising the possibility that some injuries occur under lower perceived risk conditions. This aligns with research suggesting that some concussions occur outside formal competition contexts and may go undocumented in systems focused solely on sanctioned events (Hootman et al., 2007).

Direct head contact was the most frequently reported mechanism of injury, consistent with prior post-secondary and high school surveillance findings (Kerr, Dompier, et al., 2014;

Zuckerman et al., 2015). Female athletes were disproportionately represented in equipment-related mechanisms, a pattern observed in sports such as volleyball and basketball where ball-to-head impacts and surface contact are common contributors to concussion (Bretzin et al., 2021; Covassin et al., 2013). Although mechanism data were limited by single-response reporting and incomplete case capture, the observed trends highlight the need for sport-specific prevention strategies that extend beyond traditional collision-focused paradigms (Harmon et al., 2013; Koerte et al., 2020).

Recovery Trajectories and Prolonged Symptom Duration

Recovery in this cohort was heterogeneous, with a substantial subset of athletes experiencing symptom persistence beyond the acute phase. This reinforces prior evidence that concussion recovery in adolescent and young adult athletes does not follow a uniform trajectory and cannot be adequately understood through average recovery timelines alone (Iverson et al., 2017; Kamins et al., 2017; McAllister et al., 2023).

Notably, prolonged recovery was observed across multiple sports rather than being confined to collision disciplines, reinforcing evidence that recovery duration is influenced by a complex interaction of biological, psychological, and contextual factors rather than sport contact classification alone (Howell et al., 2016; Scopaz & Hatzenbuehler, 2013). From a surveillance perspective, these findings support the importance of capturing recovery duration as more than a dichotomous outcome and reinforce the need for individualized RTP and RTL management strategies rather than relying on sport-based assumptions regarding expected recovery timelines (Echemendia et al., 2023; Iverson et al., 2017).

Academic Impact & Return-to-Learn Gaps

The academic accommodation findings highlight the significant educational consequences of concussion in a post-secondary athlete population. Collectively, the observed accommodation reporting suggests a meaningful level of academic disruption in this sample, particularly given the limited surveillance data available from post-secondary sport. Although descriptive variations were observed across grouped sport categories, these differences should be interpreted cautiously, as they likely reflect the distribution of concussion cases rather than meaningful differences in exposure-adjusted concussion risk. Academic accommodation status did not differ significantly by sex, suggesting that the educational impact of concussion was similar across male and female athletes in this sample. This pattern is broadly in line with previous literature, which has suggested a tendency for female athletes to report academic difficulties or receive support services post-concussion, but without establishing consistent sex-based differences across all settings (Covassin et al., 2016; Wasserman et al., 2016).

Given that many academic accommodations were likely undocumented (e.g., informal extensions, instructor allowances, etc.), the actual need for academic accommodations may be even higher. These findings reinforce the importance of integrating RTL processes into post-secondary concussion management, not only for elite or high-profile athletes, but across all institutions and levels of sport. While RTP remains the dominant focus in many sport medicine protocols and RTL trajectories. Standardizing RTL protocols, improving institutional awareness of concussion's educational effects, and establishing formal documentation pathways therefore represent important next steps.

Limitations

Several methodological limitations should be considered when interpreting these findings. Competition-based AE estimates do not capture practice exposures, minutes played, or positional risk and therefore likely underestimate total concussion incidence, particularly in sports with high training volume (Kerr et al., 2018; van Mechelen, 1997). Team-level roster assumptions further limit precision by assuming uniform participation across games. Although the dataset spans four academic years and includes 780 concussions from 23 of 26 OCAA institutions, the unit of analysis was the injury rather than the athlete. Without unique identifiers, repeat concussions could not be identified, introducing the potential for individual-level clustering, particularly in smaller or high-contact teams (Chandran et al., 2021; Zuckerman et al., 2015). Symptom duration should also be interpreted with caution, as no standardized follow-up protocol was in place and resolution was based on clinician judgment and athlete self-report; the absence of validated symptom tools (e.g., SCAT5) further limits interpretation of recovery severity and trajectory. Furthermore, mechanism and recovery data were limited by substantial missing data, with more than half of the cases missing symptom recovery duration and injury mechanism information. This degree of incompleteness may have reduced analytic precision and introduced bias if missingness was systematic rather than random. In addition, these variables were shaped by non-standardized reporting practices and depended in part on clinician judgment and athlete self-report, consistent with known limitations of retrospective injury surveillance systems (Iverson et al., 2017; Kerr, Dompier, et al., 2014). Reporting depth was also constrained by the data collection structure, which permitted only a single mechanism of injury and one activity context per case, limiting identification of multi-factorial or overlapping scenarios. In addition, some descriptive reporting required aggregation of sport categories to reduce small-cell

disclosure risk, which limited the granularity of sport-specific academic comparisons. Academic impact data were collected only in the post-pandemic period and captured formal accommodations only, likely underestimating the true extent of academic disruption. Finally, sex was assigned based on team affiliation rather than self-reported gender identity, limiting precision in sex-based analyses. Collectively, these limitations do not invalidate the findings but underscore persistent structural weaknesses in concussion surveillance within Canadian college sport. Despite these limitations, the integration of AE represents a substantial methodological advance over count-based reporting and demonstrates the feasibility of exposure-adjusted surveillance in resource-limited Canadian sport settings. These findings provide empirical support for the development of standardized national concussion surveillance systems incorporating exposure, recovery, and academic impact metrics (Kerr et al., 2018; van Mechelen, 1997).

Implications for Policy and Future Research

This study establishes a foundational framework for concussion surveillance within Canadian college sport. Future research should prioritize prospective data collection, inclusion of practice exposures, and incorporation of athlete-level identifiers to enable longitudinal risk assessment and recurrence analyses (Chandran, Morris, et al., 2021; Kerr et al., 2018). Expansion of surveillance systems to systematically capture RTL outcomes would further strengthen the evidence base for policy development and athlete support.

Conclusion

This study provides the first exposure adjusted characterization of SRC patterns among post-secondary student-athletes competing in the OCAA. Across four competitive seasons, SRCs were common and associated with substantial symptom duration and academic disruption. While

descriptive case counts identified sports with high concussion volume, the integration of competition-based AE demonstrated that concussion case count and concussion risk are not equivalent.

Marked sport-specific variation in SRC incidence was observed. Men's rugby exhibited the highest per exposure risk, consistent with its collision profile, while women's soccer and women's basketball demonstrated elevated incidence relative to male comparators. In contrast, sports with high raw concussion counts, most notably women's volleyball, showed more moderate incidence once exposure was considered. These findings underscore the necessity of exposure adjusted surveillance to accurately identify high-risk sports.

Nearly half of athletes with available data received at least one documented academic accommodation, highlighting concussion as both a sport-related and educational health issue within Ontario college athletics and reinforces the importance of RTL considerations in concussion management.

Despite limitations related to competition-only exposure, the findings demonstrate the feasibility and value of incorporating AE into concussion surveillance within resource-limited Canadian sport systems and provide a critical evidence base to inform injury prevention, academic support planning, and standardized surveillance development.

Chapter 4. Bridging the Surveillance Gap: A Comparative Analysis of Sport-Related Concussion Data in Canadian University and College Athletes

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Abstract

Background: SRCs are a significant health challenge in Canadian post-secondary athletics. However, surveillance efforts remain fragmented between university and college sport systems, resulting in siloed data that limit population-level risk assessment and national policy alignment.

Objective: To conduct a comparative analysis of university and college concussion datasets to evaluate sex-specific patterns, sport-type risk, and academic consequences. A primary aim was to identify converging and diverging data elements to inform a standardized national surveillance framework.

Methods: A comparative epidemiological study evaluated two independent datasets: (1) baseline focused metrics from the VADAR university team (n = 701), and (2) retrospective injury surveillance data from the OCAA (n = 780). Comparative analyses utilized harmonized variables including sex, sport contact classification, and recovery duration. Statistical evaluations involved independent t-tests, ANOVA and logistic regression to determine recovery.

Results: Female athletes demonstrated higher historical concussion prevalence (43.1% vs 30.9%) and higher pre-season baseline concussion symptom severity compared to males. While collision sports yielded the highest raw concussion counts, exposure-adjusted incidences rates in the college cohort identified a disproportionately high risk in women's soccer (11.4/1000 AE) and basketball (9.6/1000 AE). The college dataset uniquely revealed that 44% of athletes required formal academic accommodations, a metric absent from the university baseline cohort. Both datasets converged on a significant sub-population (18.8% - 30.6%) experiencing prolonged recovery exceeding 28 days.

Conclusion: Standardized concussion surveillance is essential to address the fragmented landscape of Canadian post-secondary sport. These findings support the development of a national MDS that integrates physiological assessments with athlete-exposure (AE) and academic recovery indicators. Transitioning toward evidence-based, sex-specific surveillance frameworks is a critical step in fostering athlete-centered care and equitable injury detection and prevention.

Introduction

SRCs are among the most common and complex injuries in Canadian post-secondary sport (Black et al., 2017; Echemendia et al., 2017; McCrory et al., 2017). While the clinical and public health importance of SRCs is well established, the surveillance infrastructure necessary to monitor, prevent, and respond to these injuries remains underdeveloped, particularly at the national level (Broglio et al., 2015, p. 20; Ekegren et al., 2016; Finch, 1997b). The existing landscape is characterized by data fragmentation, inconsistent practices, and variable reporting standards across institutions (Finch, 2006).

The lack of a unified concussion surveillance system in Canadian post-secondary sport has critical implications (Emery et al., 2017). In the university sector, individual institutions may utilize advanced pre-season baseline testing protocols, such as the SCAT5 or SCAT6, but rarely coordinate their data collection at a national level. In contrast, the OCAA, which governs post-secondary sport in Ontario's college system, has not historically employed standardized surveillance tools across its 26 member institutions. As a result, researchers and clinicians are left with siloed data that limit their ability to identify population-level trends, stratify risk by sport or sex, or implement evidence-informed policy.

Internationally, the National Collegiate Athletic Association Injury Surveillance Program NCAA-ISP in the United States serves as a benchmark for integrated, multi-institutional concussion monitoring (Chandran et al., 2016; Chandran, Boltz, et al., 2021; Chandran, Morris, et al., 2021). By contrast, Canadian efforts have remained largely institution-specific or research-driven (Black et al., 2017). This gap in coordination is particularly concerning given the rising incidence of concussion-related symptoms, prolonged recoveries, and academic impacts in both male and female Canadian athletes (Chandran et al., 2016; Cheng et al., 2019).

The scientific validity of Canadian post-secondary concussion research is currently constrained by the inability to synthesize data across diverse athletic environments (Billette & Janz, 2011; Canada. Parliament. House of Commons. Standing Committee on Health, 2019.; Government of Canada, 2023; *National Strategy on Brain Injuries Act*, 2025). Although the VADAR project demonstrates the capacity of university-based settings to capture physiological baseline profiles, and the OCAA dataset highlights the utility of post-secondary surveillance indicators, both remain restricted to project- or organization-specific initiatives rather than contributing to an integrated national surveillance system. This fragmentation limits comparability across settings, weakens broader epidemiologic interpretation, and constrains the development of coordinated evidence-informed policy. A significant challenge in current surveillance is the reliance on raw injury counts, which creates a conceptual trap where high-participation sports appear disproportionately risky simply because of their volume, rather than their inherent danger (Abrahams et al., 2014).

The purpose of this research is to identify the key data elements required to support the development of a standardized injury surveillance system for SRC in Canadian post-secondary athletics by comparing two distinct but complementary datasets. Rather than simply describing injury counts, this analysis examines how integrating baseline concussion symptom, concussion history, and performance indicators with exposure-adjusted incidence data can provide a more rigorous understanding of concussion patterns among Canadian post-secondary athletes (Clay et al., 2013; Comeau et al., 2023; Pierpoint & Collins, 2021).

To evaluate the scientific and methodological implications of integrating these datasets, Study 3 addresses the following objectives:

1. **Profile Comparison** – to evaluate converging and diverging patterns in concussion-related athlete demographics and clinical profiles between university-based baseline data and college-based injury surveillance data.
2. **Methodological Integration** – to assess the analytic value of incorporating AE metrics and RTL indicators within a unified surveillance framework.
3. **Minimum Data Set (MDS) Development** – to identify the core scientific variables required for a national Minimum Data Set capable of supporting interoperability between diverse institutional databases.
4. **Risk Stratification** – to demonstrate how integrating physiological baseline indicators with incident-level outcomes improves the interpretation and stratification of sex-specific and sport-specific concussion risk.

Methods

Study Design

This comparative epidemiological study analyzed variables drawn from two independent datasets: a university-based pre-season concussion baseline dataset and a college-based retrospective injury surveillance dataset. The aim of the comparison was to identify clinical and academic variables relevant to integrated concussion surveillance. By adopting a dual-lens approach, the study examined how university-based pre-season concussion baseline indicators could be conceptually compared with post-injury incident outcomes captured through college-based injury surveillance, moving beyond descriptive reporting toward a standardized framework for data interoperability.

Data Sources

Study 1: VADAR (University Cohort). Data were collected at the York University Sport Injury Clinic across three seasons (2019, 2022, 2023), excluding the 2020 – 2021 season when post-secondary sport was suspended due to the COVID-19 Pandemic. Student-athletes completed multimodal pre-season assessments that included the Sport Concussion Assessment Tool (SCAT5 in 2019 and 2022; SCAT6 in 2023), cognitive and balance testing, oculomotor and cognitive-motor integration tasks, and cerebral blood flow measures. Athletes also self-reported demographic information, history of concussion, and recovery duration from their most recent concussion. Data for this analysis were restricted to those collected using the SCAT 5/6 tools and athlete medical history and intake information.

Study 2: OCAA (College Cohort). Concussion cases were reported by Certified Athletic Therapists CAT(C) across 23 of 26 OCAA member institutions between 2018 and 2023

(excluding the 2020–2021 season, when intercollegiate sport was suspended due to COVID-19 Pandemic). Each case represented a concussion diagnosed during an OCAA-sanctioned sport. Variables included sex, sport, activity context (game, practice, training, non-sport), mechanism of injury, symptom duration, recovery duration, and academic consequences (days missed, accommodations, course load changes). Retrospective estimates of AE were generated to calculate incidence rates (IRs) per 1,000 AEs for major team sports.

Study 3: Alignment (Comparison). An analysis of studies 1 and 2 was completed by mapping variables onto three primary domains: demographic profiles, sport contact classifications, and recovery duration from prior concussion. Sport types were standardized into collision, contact and non-contact categories based on established norms (Eliason et al., 2023; Prien et al., 2018) to ensure valid inter-institutional comparisons of injury.

Participants

Study 1 (VADAR): The dataset comprised of 701 post-secondary student-athletes (353 male, 348 female), primarily first-year or rookie athletes undergoing pre-season baseline testing. Inclusion criteria required athletes to be ≥17 years and eligible for post-secondary competition and not currently diagnosed with/experiencing symptoms of a concussion. Athletes were stratified by sex and sport contact classification (i.e., collision, contact, non-contact).

Study 2 (OCAA): The dataset included 780 diagnosed concussions, submitted as independent case reports across four academic seasons. Athletes' sex was inferred based on team designation (e.g., Men's Soccer). Sport type and contact classification were standardized to align with Study 1 variables. Incidence rates (IR) were also retrospectively estimated using the

formula of total games multiplied by the estimate roster size allowing for the calculation of IRs per 1,000 AE.

$$IR = \left(\frac{\text{Total Number of Concussions}}{\text{Total Estimated Athlete-exposures (AEs)}}\right) \times 1{,}000$$

Integrated Variables and Outcomes

The research incorporated a diverse range of demographic, clinical, and academic variables across both studies. Key comparison variables can be found in **Table 25**. Demographic data collected included sex (self-reported in the university cohort and inferred from team designation in the college cohort), sport type, and sport contact classification (collision, contact, non-contact). Clinical and functional variables were assessed through baseline concussion symptom severity scores and post-injury symptom duration, with recovery outcomes categorized into clinically meaningful brackets: Normal (1–14 days), Extended (15–28 days), and Persistent (exceeding 28 days). Academic impact was quantified solely within the college cohort through documented formal accommodations and modified course loads, identifying a critical metric absent from the university baseline model.

Table 25. Comparison of Concussion Surveillance Variables Between University and College Datasets

Variable Domain	Available VADAR (Study 1 – University)	Available OCAA (Study 2 – Colleges)	Comments / Alignment Potential
Sex	✓ Self-reported (M/F)	✓ Inferred from team designation	Aligns on binary categories only. No sex identity was collected in either dataset.
Age	✓ Exact age collected	✗ Not available	Cannot align.
Sport	✓ Multiple sports, U SPORTS roster	✓ Multiple sports, OCAA roster	Aligns. OCAA has baseball/softball, not present in VADAR.
Sport contact classification	✓ Categorized: collision, contact, non-contact	✓ Post-hoc classification applied	Aligns directly.
Concussion history (HOC/RHOC)	✓ Self-reported number and timing of prior concussions	✗ Not available	Unique to VADAR.
Most recent recovery duration (days)	✓ Self-reported for athletes with prior concussion	✓ Therapist-reported symptom duration per case	Aligns conceptually (recovery) but measured differently.
SCAT5/SCAT6 baseline data	✓ SCAT5 (2019, 2022) and SCAT6 (2023)	✗ Not collected	Unique to VADAR.
Concussion Symptom severity (baseline)	✓ SCAT checklist scores	✗ Not collected	Unique to VADAR.
Symptom duration (post-injury)	✗ Not collected (except retrospective recovery)	✓ Days symptomatic tracked per case	Unique to OCAA, but both allow categorization into recovery brackets.
Academic accommodations	✗ Not collected at baseline	✓ Documented Y/N (post-2021)	Unique to OCAA measures directly.
Days missed (school, games, practices)	✗ Not collected	✓ Available (2018–2020 only)	Unique to OCAA measures.
Return-to-play data	✗ Not collected	✗ Not collected	Not directly available in either dataset.
Return-to-learn data	✗ Not collected	✓ Indirectly via accommodations	Unique to OCAA.
Athlete-exposure (AE)	✗ Not available	✓ Estimated retrospectively (games × roster size)	Derived outcome; not directly collected.
Concussion incidence rates (IR)	✗ Not available	✓ Calculated per 1,000 AEs	Derived outcome; not directly collected.

Table 25 compares the availability of key demographic, sport-related, clinical, and academic variables across the VADAR and OCAA datasets, highlighting shared and unique measures that inform recommendations for future consideration.

To facilitate cross-study comparison, variables from the VADAR (Study 1) and OCAA (Study 2) datasets were mapped to identify points of alignment and divergence. Table 25 summarizes available measures across both cohorts, highlighting common domains (e.g., sex, sport, sport contact classification, recovery duration) as well as unique features of each dataset. While VADAR provided rich baseline assessments, including SCAT5/ SCAT6 pre-season symptom severity reports and self-reported history of concussion, OCAA offered incidence-based surveillance with exposure-adjusted rates, therapist-documented symptom duration, and academic accommodations. This comparison mapping underscores that while direct pooling of data was not possible, parallel analyses across shared variables allowed for meaningful comparative insights into concussion risk and recovery in university versus college settings.

Statistical Analyses

Descriptive statistics (Means, *SD*s, proportions) summarized demographic and injury-related characteristics within each dataset. Inferential analyses included independent-samples *t*-tests and ANOVAs for continuous variables (e.g., recovery duration, symptom scores), and chi-square tests for categorical variables (e.g., sex differences in concussion prevalence). Logistic regression was applied in Study 1 to evaluate factors associated with prolonged recovery (defined as symptoms duration exceeding 28 days based on self-report from most recent concussion). Incidence rates with 95% confidence intervals were calculated for Study 2 based on AEs. Comparative analyses focused on compatible variables (sex, sport type, recovery duration categories), presented descriptively to highlight converging and diverging patterns across

university and college cohorts. Harmonization relied on post-hoc variable mapping rather than shared prospective definitions; findings should be interpreted as comparative rather than pooled.

Ethics

Ethical approval for both studies was obtained from the York University's Human Participants Review Committee; Certificate #: e2019-283 and e2024-231). Study 1 obtained informed consent from all participants prior to baseline testing. Study 2 involved secondary analysis of de-identified data, with formal data-sharing agreements between York University and the OCAA, consistent with the Tri-Council Policy Statement on the ethical use of secondary health data.

Results

Participant Overview

The university (VADAR) cohort included 701 post-secondary student-athletes (353 male, 348 females; $M = 19.8 \pm 1.9$ years) who completed baseline pre-season concussion assessments between 2019 and 2023. By contrast, the college (OCAA) dataset comprised 780 diagnosed concussions reported by CAT(C)'s across 23 member institutions between 2018 and 2023. Sex distribution differed between cohorts: VADAR athletes were evenly split, whereas females accounted for a higher proportion of OCAA concussion cases (58.2%). Demographic data such as age were unavailable in the OCAA dataset due to the nature of the surveillance reporting forms (**Table 26**).

Comparative Insight: Participants

VADAR reflects athlete-level baseline profiles prior to competition, whereas OCAA represents injury-level surveillance of concussions sustained during the years collected. The difference in scope highlights the complementary strengths of the two systems: universities capture *who is entering the sport* (population risk), while colleges capture *who sustains injury* (incident cases). The overrepresentation of females among concussion cases (~50%) suggests a sex-specific disparity in reported incidence that warrants targeted surveillance.

Table 26. Participant Overview Across Studies

Variable	VADAR (Study 1 – University)	OCAA (Study 2 – College)
N	701 (Baseline Athletes)	780 (Diagnosed Concussions)
Sex (% female)	49.6%	58.2%
Age ($M \pm SD$)	19.8 ± 1.9 years	N/A
Data Scope	Pre-season Baseline	Post-injury Surveillance

Notes. M: Mean; OCAA: Ontario Colleges Athletic Association; SD: Standard deviation; VADAR: Varsity Athlete Data Analysis Research

Concussion History vs. Concussion Incidence

In the VADAR cohort 36.3% of the athletes RHOC, with a significantly higher prevalence among females (43.1%) compared to males (30.9%). These historical injuries were clustered primarily in collision sports, including football, rugby, and hockey. Conversely, the OCAA dataset enabled estimation of sport-specific concussion risk through exposure-adjusted IRs. Men's rugby demonstrated the highest IR at 36.4 per 1,000 AEs, followed by Women's Rugby Sevens (15.0), Women's Soccer (11.4), and Women's Basketball (9.6). While sports such as men's soccer and volleyball had higher numbers of reported concussions, they yielded lower IRs (4.8 and 2.9, respectively), illustrating the discrepancy between injury counts and actual risk.

Comparative Insight: Concussion History and Incidence

The synthesis of these datasets reveals that concussion risk is a twofold phenomenon: a combination of historical biological risk (i.e., female athlete) an athlete carries into the season (VADAR) and the real-time environmental risk they face during competition (OCAA).

A critical implication of these findings is the identification of a conceptual pitfall. In the OCAA cohort, Women's Volleyball produced a high absolute number of concussions (n = 100), but a relatively low IR (6.0) once adjusted for participation volume. Without AE denominators, institutions might misallocate medical resources toward high-participation sports while overlooking high-risk, lower-participation environments like Women's Rugby Sevens which demonstrated an incidence of 15.0 per 1,000 AEs. This finding further emphasizes that the scientific validity of any surveillance system is fundamentally reduced if it relies solely on injury counts.

The finding that nearly half of female athletes enter the post-secondary system with a pre-existing history of concussion (43.1%) while simultaneously sustaining new injuries at higher rates in sports like soccer and basketball suggest a cycle of cumulative risk. This indicates that RTL and RTP protocols should be more sensitive to baseline vulnerability in women's athletics, as the lack of exposure data in many university settings currently acts as a blind spot in these compounded risks.

Concussion Symptom Count and Recovery Duration

Recovery trajectories diverged significantly between the two datasets, reflecting differences in both timing and measurement methodology. In the VADAR cohort, 30.6% of

athletes with a RHOC reported persistent symptoms lasting more than 28 days following their most recent concussion, based on retrospective self-report rather than baseline symptom assessment. Females demonstrated longer recovery times than males, particularly within collision sport categories. In the OCAA cohort, therapist-reported recovery duration averaged 17.2 days (*SD* = 25.7). Distribution of recovery in the college cohort showed that 39.8% of athletes recovered within 1 - 7 days, 27.8% within 8 -14 days, and 14.2% experienced prolonged symptoms exceeding 28 days (see **Figure 5**). The OCAA dataset captured a wide range of acute recovery, spanning from 0 to 220 days, providing a prospective view of clinical resolution (See **Table 27**).

Comparative Insight: Concussion Symptoms and Recovery

Despite differences in measurement VADAR's retrospective self-report versus OCAA's prospective therapist documentation, both cohorts identify the presence of a substantial subgroup with prolonged recovery (>28 days). This consistency between data sources underscores that persistent post-concussion symptoms are a systemic reality across all levels of post-secondary sport.

However, the divergence between VADAR's 30.6% and OCAA's 14.2% prolonged recovery rates emphasizes a methodological difference in concussion research. The discrepancy highlights the differences between recall bias and clinical reality.

Table 277. Symptom Recovery Across Studies

Recovery Metric	VADAR (Study 1 – Self-reported)	OCAA (Study 2 – Therapist-documented)
Mean Duration (days)	~45 days (retrospective)	17.2 days
Prolonged Recovery (>28 days)	30.6% (RHOC athletes)	14.2% (of incident cases)
Dominant Recovery Window	Persistent (>28)	Acute (1 – 14 days)

Notes. OCAA: Ontario Colleges Athletic Association; RHOC: Reported History of Concussion; VADAR: Varsity Athlete Data Analysis Research

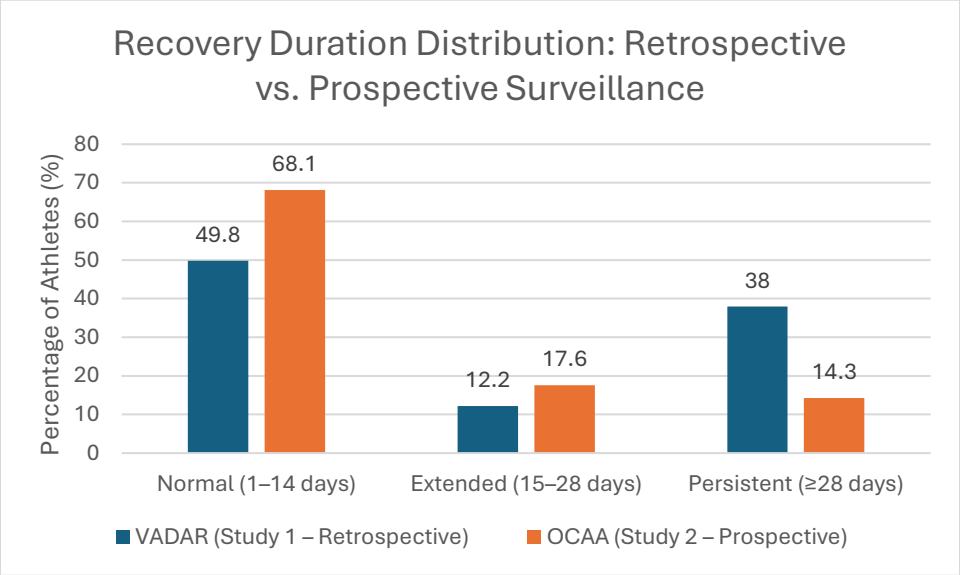


Figure 5. *Recovery Duration Distribution*

Sex Differences

Sex-based disparities were evident across both datasets, though expressed in different clinical and epidemiological ways. In the VADAR cohort, female athletes were more likely to report previous history of a concussion (43.1% vs. 30.9%) and demonstrated higher pre-season concussion baseline symptoms and severity scores on the SCAT5/6. Females were also 2.3 times more likely to experience prolonged recovery (>28 days) compared to males.

In the OCAA incident-based cohort, females represented many concussion cases (58.2%), despite a more balanced participation. However, within the OCAA cohort, no significant sex-based differences were observed in recovery duration ($p = 0.26$). A notable difference did emerge in the mechanism of injury: females accounting for 76% of in equipment-related concussions.

Comparative Insight: Sex Differences

Taken together, these findings suggest that sex differences in concussion are visible across both datasets, but that their meaning depends on the type of surveillance being used. The VADAR dataset identifies sex-based differences in pre-injury symptom reporting, concussion history, and self-reported recovery from prior concussion, whereas the OCAA dataset captures how sex differences appear in incident patterns and mechanisms within a clinically monitored sport environment.

The contrast between studies indicates that baseline and retrospective symptom-based data may emphasize perceived or recalled burden, while incident surveillance data are better positioned to characterize how concussion presents within real-time clinical care. This comparison reinforces the value of integrated surveillance, as sex-related concussion patterns cannot be fully understood through baseline assessment or injury surveillance alone. Across the two datasets, sex differences manifested distinctly: VADAR identified higher concussion history (43% vs. 31%) and 2.3-fold greater odds of prolonged recovery among female athletes, whereas the OCAA cohort showed no significant sex difference in recovery duration but disproportionate female representation in equipment-related mechanisms (76% of cases).

Sport-Specific Risk: Raw Counts vs. AE-Adjusted Rates

Both datasets implicate collision sports as the primary drivers of concussion risk, although the integration of AE data in the OCAA cohort provides necessary epidemiological nuance. In the VADAR cohort, raw proportions of RHOC indicated that athletes in football, rugby, and hockey carried the greatest historical impact. However, exposure-adjusted IRs from the OCAA dataset revealed a more nuanced risk profile. Men's Rugby demonstrated the highest IR (36.4 per 1,000 AEs), while women's contact sports such as soccer (11.4 per 1,000 AEs) and basketball (9.6 per 1,000 AEs) also exhibited elevated rates relative to other sports. In contrast, Women's Volleyball accounted for a high number of reported concussions (n = 100) but a lower IR (6.0 per 1,000 AEs) after accounting for AE (**Table 30**).

Comparative Insight: Sport-Specific Risk

The most significant finding in this section is the shift in interpretation of SRC risk when moving from injury counts to AE-adjusted IR. For example, Women's Soccer reported more raw injuries (n = 121) than Men's Rugby (n = 109), however the IR in rugby was more than three times higher. This demonstrates that raw counts can obscure the true intensity of risk in low-participation or short-season sports, such as rugby.

While Study 1 (VADAR) indicates that athletes participating in collision sports report a greater historical prevalence of concussion, Study 2 (OCAA) shows that several contact sports, including soccer and basketball, also experience elevated IRs when athlete-exposure is considered. These contrasting patterns of injury volume and exposure-adjusted risk suggest that prevention approaches may need to be sport-specific rather than uniformly applied across sports. High-participation sports with lower IR (e.g., volleyball) and lower-participation sports with higher IRs (e.g., rugby) may therefore require different prevention considerations, as supported

by prior sport injury prevention literature (Bahr & Krosshaug, 2005; Finch, 2006). For example, the observation that contact sports such as basketball (9.6 IR) demonstrate higher IRs than other contact sports that involve intentional head contact, such as soccer (4.8 IR for males), highlights the limitation of traditional sport classification systems for identifying injury risk.

These findings suggests that surveillance frameworks should prioritize exposure-adjusted IRs when identifying high-risk sports, rather than relying solely on conventional sport contact classifications. Incorporating real-time IR monitoring within a national MDS could therefore improve the precision of risk identification and better inform targeted prevention strategies.

Table 28. Sport- Specific Concussion Symptom Count

Sport	VADAR (Study 1: % with prior concussion)	OCAA (Study 2: incidence per 1,000 AEs)
Football	16.9% (highest among men)	N/A
Rugby	High PHC in Women's Rugby	36.4 (Men's), 15.0 (Women's
Hockey	High PHC in both sexes	Not consistently reported
Soccer	Moderate PHC rates	11.4 (Women's), 4.8 (Men's)
Basketball	Moderate PHC rates	9.6 (Women's), 4.9 (Men's)
Volleyball	Lower PHC	3.8 (Women's), 2.9 (Men's)

Note. AE: Athlete Exposure; PHC: Previous History of Concussion; OCAA: Ontario Colleges Athletic Association; VADAR: Varsity Athlete Data Analysis Research

Academic Consequences (Unique to OCAA)

The OCAA dataset uniquely captured the educational impact of concussion, a metric absent from the VADAR baseline model. Among 318 cases with complete academic data, 44% of athletes required formal accommodations, which could include exam deferrals, assignment extensions, and modified course loads. While these outcomes were not significantly associated with sex ($p = 1.00$), descriptively higher accommodation rates were observed in women's basketball and volleyball.

Comparative Insight: Academic Outcomes

The inclusion of academic outcomes in the OCAA dataset highlights an important dimension of concussion impact that remains invisible in baseline-only models such as VADAR. Whereas VADAR can characterize pre-injury symptom presentation and concussion history, it cannot determine whether concussion disrupts educational participation or creates a need for formal RTL support. As nearly half of athletes with complete academic data required accommodations it is clear that the impact of concussions in post-secondary sport extends beyond clinical recovery alone and into academic functioning. This comparison underscores that surveillance systems excluding RTL indicators are likely to underestimate the full impact of concussion on student-athletes and may overlook information that is directly relevant to institutional decision-making and support planning. Among 318 OCAA cases with complete academic data, 140 (44.0%) received at least one formal academic accommodation, with no significant sex-based association ($p = 1.00$); this metric was not captured in the VADAR baseline model.

Discussion

This comparative analysis reveals substantial methodological and contextual disparities between concussion surveillance practices in Canadian university (VADAR) and college (OCAA) sport. While both datasets report elevated concussion risk among female athletes and high incident counts in collision sports, the divergence in surveillance, specifically regarding AE data and academic recovery tracking yields distinct strengths and limitations for informing institutional alignment. The integration of AE-adjusted IRs in the OCAA dataset provides a more accurate portrayal of sport-specific risk than raw counts alone. These findings from the OCAA cohort challenge the traditional contact/non-contact binary, as sports like women's basketball and soccer demonstrated elevated IRs that rival or exceed traditional collision sports, such as rugby and football. This suggests that without denominator data, as seen in the VADAR dataset, even sophisticated clinical tools lose their interpretive value, with higher numbers of reported concussions that may appear disproportionately risky in the absence of exposure-adjusted IRs. Therefore, a standardized national framework should mandate AE tracking to avoid relying on raw concussion incident counts in place of IRs, ensuring that resources are allocated based on exposure-adjusted risk rather than counts alone. The divergence in recovery patterns between the two cohorts further illustrates the challenge between retrospective baseline profiling and real-time clinical tracking. VADAR baseline data revealed significantly higher self-reported symptom scores and more frequent histories of prolonged recovery exceeding 28 days, particularly among female athletes. In contrast, the OCAA data offered a clearer picture of acute recovery timelines, identifying that the majority of student-athletes resolve within the standard 14-day clinical window. Together, these approaches demonstrate that a combined surveillance model is essential; universities identify who carries historical vulnerability into competition, while colleges identify

the real-time clinical resolution of new injuries. This combination indicates that neither system is sufficient in isolation, both retrospective and prospective data must be incorporated to capture the full trajectory of the injury and recovery.

Perhaps the most significant divergence identified in this research lies in the inclusion of academic outcome variables. The OCAA dataset's tracking of academic accommodations post-concussion revealed that nearly half of all affected athletes required academic support, a metric that was absent from the university-based VADAR dataset. This gap underscores a critical omission in many current concussion surveillance systems: the educational impact of brain injury. By excluding RTL metrics, university systems may be missing key indicators of functional recovery and failing to address the primary responsibility of the student-athlete. Concussion must therefore be viewed not just as a medical event, but as a potential academic crisis; integrating academic impact tracking is a prerequisite for fostering equitable student-athlete well-being and ensuring that educational equity is maintained across diverse institutional contexts.

A further methodological consideration relates to the interpretive ambiguity of post-injury symptom reporting in the absence of pre-injury affective baseline data. Several symptoms used to monitor concussion recovery including irritability, sadness, anxiety, fatigue, and difficulty concentrating overlap substantially with symptoms of general anxiety and depression that may be present prior to injury. In Study 1, for example, female athletes endorsed "nervous or anxious" at a significantly higher rate than males at baseline (32.7% vs. 21.3%, $p = .012$), highlighting the importance of distinguishing pre-existing affective symptomatology from concussion-attributable symptom emergence. Without a pre-injury anchor, post-injury elevations on these items risk being misinterpreted as concussion sequelae when they may reflect stable individual

characteristics. Surveillance systems that incorporate brief, validated pre-season screens for anxiety and depression (e.g., GAD-2, PHQ-2) added here as Tier 2 variables in Appendices A and B would enable more accurate attribution of recovery symptoms and improve the interpretability of return-to-learn and return-to-play decisions.

The differences identified between the VADAR and OCAA datasets should be viewed not as methodological obstacles, but as strategic opportunities to inform a more complete national approach. These findings support the urgent need for a nationally standardized concussion-specific surveillance framework that includes standardized physiological assessments, AE-adjusted incidence metrics, and academic impact tracking. While similar principles could inform surveillance of other injuries (e.g., musculoskeletal conditions), the present findings specifically highlight gaps in concussion monitoring within Canadian post-secondary sport. Furthermore, given the consistent observation of higher concussion incidence among female athletes across both baseline and injury surveillance contexts, future concussion surveillance systems should mandate sex-disaggregated reporting to ensure a more equitable and accurate representation of the injury landscape on which institutional decisions can be based. The proposed national MDS therefore provides a foundational framework for surveillance standardization, enabling the Canadian post-secondary sport system to move beyond fragmented data collection toward a proactive, coordinated infrastructure capable of informing prevention, policy and athlete support.

Limitations

The limitations of this comparative analysis are largely inherited from those of the contributing datasets and are described in detail in Chapters 2 and 3. In brief, Study 1 (VADAR) was constrained by self-reported concussion history and recovery duration, missing data on recovery time among athletes with reported prior concussion, single-institution sampling, and the

absence of post-injury surveillance data. Study 2 (OCAA) was constrained by the absence of practice exposure data, the use of injury rather than athlete as the unit of analysis (precluding identification of repeat concussions), inconsistent capture of academic outcomes across reporting years, single-mechanism reporting restrictions, and inference of sex from team designation. The comparative analysis in this chapter inherits both sets of limitations and adds one additional constraint: the two datasets were not designed for harmonized analysis, so cross-study comparisons relied on post-hoc variable mapping rather than shared prospective definitions, and findings should therefore be interpreted as comparative rather than pooled (Bahr et al., 2020b; Costello et al., 2024).

Rather than restating findings from the contributing studies, the recommendations that follow translate these collective limitations into surveillance design priorities. This framing reflects the central argument of the dissertation: that fragmented surveillance infrastructure not isolated methodological choices within any single study is the primary barrier to interpretable concussion epidemiology in Canadian post-secondary sport.

Recommendations

These recommendations are informed by several methodological constraints identified across Studies 1 and 2 including the absence of practice exposure data, the inability to distinguish primarily starting athletes from those with limited playing time (i.e., athletes not in the starting lineup). The lack of athlete-level identifiers preventing recurrence analysis, and inconsistencies in academic outcome reporting represent surveillance gaps that are addressable through prospective, iterative system design rather than discrete methodological adjustments. While the present analyses are limited to retrospective data, the recommendations below are

framed as forward-looking surveillance priorities intended to close these gaps in subsequent cycles of implementation.

The exclusion of practice exposure is illustrative. Although the present analyses confirmed that the majority of OCAA concussions occurred during competition, practice represents the dominant component of total athlete exposure in nearly every sport, and prior surveillance literature consistently demonstrates that practice-related injuries contribute meaningfully to overall sport-related injury burden (Hootman et al., 2007; Kerr et al., 2018). Excluding practice exposure therefore systematically truncates the denominator and may underestimate true sport-specific concussion risk, particularly in training-intensive sports such as volleyball and basketball. Capturing practice exposure is also necessary to interpret risk equitably across rostered athletes, as starters and frequently substituted players accumulate substantially more game-based exposure than non starting players, while practice exposure is more evenly distributed across the roster. Without practice data, surveillance estimates implicitly characterize the risk profile of high-participation athletes rather than that of the full sport population.

These gaps are best addressed through staged implementation rather than retroactive correction. The recommendations are operationalized through a proposed tiered Minimum Data Set (MDS; **Appendix A** and **B**), mapped to feasible institutional data elements (**Appendix C**), and summarized as a minimal viable dataset to support staged national implementation (**Appendix D**). A pilot evaluation, supported by the surveillance performance indicators outlined in Appendix E, would also allow benchmarking of data completeness, timeliness, and inter-rater reliability across institutions of differing resource capacity. Treating surveillance development as an ongoing, evaluable process rather than a one-time deployment is consistent with established

frameworks for sport injury prevention research, in which surveillance is positioned as a continuous feedback system rather than a static data-collection exercise (Bahr et al., 2020b; Finch, 2006).

The recommendations that follow are organized around two intersecting and sometimes competing principles: feasibility and standardization. Feasibility refers to the practical capacity of post-secondary institutions to implement a given surveillance element given existing staffing, technology, and resource constraints (ex. what can realistically be collected within the operational realities of CAT(C)s, athletic therapy clinics, and institutional administration). Standardization refers to the degree to which a variable is defined, measured, and recorded consistently across institutions, such that data can be meaningfully aggregated for national-level analysis. The two principles are not always aligned. Variables that are easy to collect at one institution may be defined differently elsewhere, and rigorously standardized variables may impose data-capture challenges that exceed local capacity. The tiered Minimum Data Set framework presented in Appendix B explicitly reflects this tension: Tier 1 (Core) variables are those that are both feasible across institutions of differing resource levels and sufficiently well-defined to support national comparability, while Tier 2 (Enhanced) and Tier 3 (Supplemental) variables expand surveillance richness as institutional capacity permits. Recommendations should therefore be evaluated not only on scientific merit but on the practical achievability and definitional consistency required to make national surveillance interpretable.

Recommendation 1: Establish a National Minimum Data Set (*Appendix A*; MDS): The integration of the evaluated datasets provides a framework that would mandate the collection of core demographic variables (sex, age, sport, contact type) to facilitate risk stratification and inter-institutional benchmarking (Finch, 2006; World Health Organization, 2001).

Furthermore, the MDS should integrate clinical and functional indicators such as the specific mechanism of injury, concussion symptom severity measured through validated tools, and total symptom duration (Broglio et al., 2015; Echemendia et al., 2023). The MDS should move beyond purely medical metrics: the inclusion of academic impact variables, such as formal accommodations and total days of school missed, is essential to capture the real-world functional impact of concussions and ensure that educational equity is maintained throughout the recovery process (McAvoy et al., 2018; Sady et al., 2011). By aligning these diverse data elements into a single, interoperable architecture, the Canadian post-secondary sport system can transition toward a proactive, evidence-based standard of care that supports both the athletic and academic success of the student-athlete (Wilkinson et al., 2016).

Recommendation 2: Require Athlete-exposure (AE) Tracking: Injury counts alone are not sufficient for evaluating sport risk (Bahr & Krosshaug, 2005). Institutions should therefore collect AE data (e.g., games × roster size or athlete-hours) to enable valid IR calculations (Bahr et al., 2020b; Broglio et al., 2014). Exposure tracking should include both competition and practice participation, as training sessions often represent the largest source of AE in many sports (e.g., volleyball), and excluding these exposures may distort estimates of true injury risk. Where feasible, exposures should be captured using standardized metrics, such as athlete participations in games and practices or athlete hours of participation. Institutional support and targeted funding may be required to facilitate exposure estimation through mechanisms such as coach logs, scheduling software, or wearable technologies.

Recommendation 3: Integrate Academic Recovery Metrics: Return-to-learn (RTL) tracking should be a core component of concussion surveillance. Institutions should report whether formal academic accommodations were issued, type of supports provided, and total days

missed. These data inform functional recovery timelines and can guide RTL policy (McAvoy et al., 2020; Pei et al., 2023).

Recommendation 4: Establish National Data Sharing Infrastructure: Federal or provincial bodies (e.g., Canadian College Athletic Association, U SPORTS and OCAA) should coordinate a centralized database that aggregates de-identified SRC data across institutions. This would mirror models like the NCAA-ISP in the United States and enable real-time surveillance, benchmarking, and research access (Chandran, Morris, et al., 2021; Costello et al., 2024).

Recommendation 5: Mandate Sex-Specific Reporting: Given consistent findings of sex-based differences in symptom expression, reporting, and recovery, all SRC surveillance should be disaggregated by sex (Bretzin et al., 2018; Covassin et al., 2016). Policy responses must consider these disparities to ensure equitable prevention and treatment strategies.

Recommendation 6: Incentivize Multimodal Data Collection: Future funding should prioritize surveillance systems that integrate real-time injury tracking (e.g., OCAA's therapist-submitted forms) with a baseline screening process (e.g., VADAR's SCAT5/6 model). A hybrid model will yield the richest epidemiological and clinical insights.

Implementing these recommendations will require balancing standardization against feasibility at every stage. Institutions with limited staffing or competing administrative priorities may initially adopt only the Tier 1 (Core) elements of the MDS, while well-resourced institutions can expand to Tier 2 (Enhanced) or Tier 3 (Supplemental) variables. Standardization should not be interpreted as requiring uniform infrastructure across institutions; rather, it requires that core variable definitions remain consistent regardless of where or how data are collected. Where

feasibility constraints limit consistent capture of a variable, transparent documentation of measurement variability is preferable to forced standardization that compromises data quality. The goal is not a single uniform system, but a shared analytic vocabulary that allows institutional data to remain interpretable in aggregate.

By aligning institutional practices under a shared national standard, Canadian sport can shift from reactive to proactive concussion management supporting not just supporting athlete safety, but also educational equity and long-term well-being.

Conclusion

This comparative analysis provides a critical examination of the fragmented landscape of SRC surveillance within Canadian post-secondary athletics. By contrasting two independent datasets, one from high-resource university baseline measures and the other in real-world college injury surveillance, this research demonstrates how differences in data architecture alter the interpretation of injury risk, recovery trajectories, and functional impact. These findings highlight that while sophisticated clinical tools like the SCAT6 offer detailed physiological insights, their utility is significantly diminished without the inclusion of AE metrics to provide necessary epidemiological context. The current siloed practices are not sufficient for a comprehensive understanding of the impact of concussions in the post-secondary setting, particularly concerning the disproportionate risks faced by female student-athletes.

Ultimately, the necessity of integrating multimodal assessment tools with sound exposure metrics and academic recovery indicators cannot be overstated. To move the field forward, Canadian post-secondary institutions must move beyond the mere counting of injuries and toward a nationally holistic and standardized surveillance framework. The proposed MDS

provides a foundational blueprint for this evolution, offering a standardized pathway to capture not only who is injured, but how those injuries impact the athlete both on the field and in the classroom. Implementing this model through a coordinated effort between national sport and health agencies will allow the Canadian athletic system to transition from a reactive posture to a proactive, evidence-based standard of care. Only through such standardization can institutions fully address the clinical and educational impact of concussions, ensuring the long-term well-being and equitable treatment of all student-athletes.

Chapter 5. General Discussion

Surveillance Systems as Determinants of Concussion Knowledge in Post-Secondary Institutions

Sport-related concussion in post-secondary athletics is often characterized as a condition defined by clinical heterogeneity, variable symptom expression, and inconsistent recovery trajectories. While these features are real, their prominence in the research discourse has obscured a more foundational issue: the extent to which concussion in post-secondary sport remains poorly understood is driven less by intrinsic clinical uncertainty than by the structure and limitations of the surveillance systems through which concussion is observed, recorded, and interpreted. Apparent inconsistencies in risk estimates, recovery timelines, and outcome prevalence may therefore reflect methodological fragmentation embedded within the Canadian post-secondary sport landscape rather than irreducible clinical ambiguity.

Injury surveillance systems are not passive repositories of clinical events (Bahr et al., 2020b; Ekegren et al., 2016). Rather, they function as measurement infrastructures that determine what can be measured, compared, and inferred. Data system design shapes whether injury is conceptualized as an isolated clinical episode or as part of a broader functional trajectory; whether risk is expressed as frequency or incidence; and whether recovery is defined narrowly by symptom resolution or expansively by academic and psychosocial reintegration. These design decisions, often made for pragmatic or administrative reasons, profoundly influence the knowledge generated and the conclusions drawn (Finch, 2006; Wilkinson et al., 2016).

Within Canadian post-secondary sport, data system fragmentation is particularly pronounced. Canadian post-secondary institutions operate under distinct organizational mandates, medical infrastructures, and reporting mechanisms, resulting in parallel data systems that capture different dimensions of concussion experience (Bang et al., 2020; Emery et al.,

2017). Baseline-oriented systems emphasize athlete characteristics, prior injury history, and pre-participation vulnerability, but often lack the longitudinal injury detail necessary to contextualize acute events. Clinical injury surveillance systems prioritize incident documentation and medical management, yet frequently omit baseline context, exposure normalization, and downstream functional outcomes. Each system is internally coherent, but neither independently supports comprehensive inference regarding risk, recovery, or impact.

The co-existence of these surveillance paradigms has contributed to a literature in which concussion risk appears inconsistently distributed across sports, sexes, and competitive contexts, and where recovery timelines vary widely even among comparable populations. However, many discrepancies are likely attributable to differences in measurement architecture. Retrospective self-report systems capture cumulative exposure and persistent symptoms differently than prospective clinical documentation. Systems that lack exposure data necessarily conflate participation volume with injury tendency (Bahr et al., 2020b; Kerr, Register-Mihalik, et al., 2014), while systems excluding academic or psychosocial outcomes implicitly privilege clinical clearance as the endpoint of recovery. Surveillance design thus shapes the contours of scientific interpretation.

These structural features carry implications beyond academic discourse. In the absence of harmonized surveillance standards, institutional comparisons are inherently unstable, national estimates lack coherence, and policy decisions are often informed by incomplete or non-comparable evidence. Risk classification may be distorted, resource allocation misdirected, and prevention strategies evaluated against metrics that do not align with athlete experience. Importantly, these limitations persist even in the presence of high-quality clinical care and

diligent data collection, underscoring that the issue is structural rather than procedural (Bahr et al., 2020b; Costello et al., 2024).

This dissertation therefore advances an integrated analytic approach across different surveillance systems to interrogate not only patterns of concussion, but the conditions under which those patterns become interpretable. By examining baseline vulnerability, injury occurrence, exposure-adjusted risk, and functional outcomes within a single analytic framework, it would be possible to identify not only patterns of concussion incidence and recovery, but also the methodological conditions under which those patterns emerge. The central contribution of this dissertation lies in demonstrating that surveillance architecture is a primary determinant of interpretability in post-secondary concussion research. Recognizing surveillance as infrastructure – rather than afterthought – is a prerequisite for advancing both scientific understanding and evidence-informed policy in post-secondary sport. This chapter synthesizes the findings of the three studies and situates them within the broader methodological landscape of concussion surveillance in post-secondary sport.

Sex Differences as a Function of Surveillance Design

Sex-based differences in SRC have emerged as one of the most frequently cited and least consistently interpreted findings in the post-secondary concussion literature. Across multiple study designs, female athletes are often reported to experience higher concussion incidence, greater baseline symptom score, and longer recovery durations than their male counterparts (Bretzin et al., 2021; Cheng et al., 2019; Covassin et al., 2016; Iverson et al., 2017). While biological, biomechanical, and psychosocial mechanisms have been proposed to explain these patterns, such explanations are frequently advanced without sufficient consideration of how

surveillance structure conditions the observation and interpretation of sex differences in the first place.

Surveillance systems determine not only whether sex differences are detectable, but also how those differences are operationalized and contextualized. Retrospective, baseline-oriented systems rely on self-reported concussion history, cumulative symptom exposure, and recovery experiences (Bruce & Echemendia, 2009; Covassin et al., 2008). Within these frameworks, sex differences are often amplified, as reporting thresholds, recall processes, and symptom attribution may vary systematically by sex. In contrast, prospective clinical surveillance systems prioritize acute injury documentation and medically supervised recovery, frequently constraining recovery duration to institutionally defined clearance processes. These systems may attenuate observed sex differences by emphasizing standardized clinical endpoints while minimizing longer-term or non-clinical sequelae (Bahr et al., 2020b; Chandran, Boltz, et al., 2021; Finch, 1997b; Kerr, Register-Mihalik, et al., 2014).

The result is a literature characterized by recurring evidence of sex differences, although their magnitude, direction, and interpretation remain inconsistent across studies. This variability is often treated as evidence of complex or interacting biological mechanisms, when it may more accurately reflect differences in what each surveillance system is capable of detecting. Systems that privilege symptom self-report over functional impact capture a different dimension of recovery than those that privilege return-to-play (RTP) clearance. Neither perspective is inherently incorrect; however, each produces a partial account that becomes misleading when interpreted as comprehensive.

The absence of standardized exposure data further complicates interpretation. When incidence is expressed without normalization to participation volume or event exposure, apparent

sex differences may reflect structural participation patterns rather than differential susceptibility. Sports with higher female participation or longer competitive seasons may produce more injuries simply because they involve more opportunities for exposure. Without consistent exposure metrics, disentangling biological vulnerability from structural exposure remains speculative (Finch, 1997b).

This dissertation treats sex differences as both robust and unstable, frequently observed, yet variable in magnitude and interpretation. Although biological heterogeneity likely contributes to these patterns, part of the observed variability may also reflect differences in what surveillance systems are capable of detecting. Systems that use symptom self-report capture subjective symptom persistence and perceived recovery, whereas those emphasizing RTP clearance prioritize clinical decision thresholds and institutional clearance protocols. Neither approach is inherently deficient; each produces a partial representation that becomes misleading when interpreted as comprehensive.

Examining sex-based patterns across systems that differ in temporality, outcome definition, and exposure capture allows for the identification of findings that remain consistent across frameworks versus those contingent upon them. Such differentiation is essential for moving beyond descriptive comparison toward more valid epidemiologic inference.

Risk Misclassification in Post-Secondary Concussion Research and the Central Role of Exposure

Risk estimation in post-secondary SRC research has traditionally relied on injury counts or crude incidence measures that do not account for differential exposure to sport participation (Finch, 2006). While such approaches offer descriptive insight, they obscure the distinction

between injury impact and injury risk, leading to systematic misclassification that persists across the literature. In post-secondary sport, where participation volume, training frequency, and competitive density vary widely by sport, sex, and institution, failure to incorporate exposure fundamentally limits interpretability.

Injury counts are often interpreted as indicators of risk, despite reflecting a composite of participation volume, surveillance intensity, and reporting opportunity (Chandran, Morris, et al., 2021; Kerr, Register-Mihalik, et al., 2014). Sports characterized by large rosters, extended seasons, or frequent training sessions naturally generate more injury events, independent of per-exposure susceptibility. Without adjusting for the number of participants and frequency of exposure, these structural features are misattributed to intrinsic risk. This issue is compounded in post-secondary settings, where institutional variation in scheduling, medical coverage, and documentation practices further decouples injury frequency from true exposure-adjusted incidence.

Exposure-adjusted metrics provide the necessary corrective framework by contextualizing injury occurrence relative to participation opportunity. However, inconsistent exposure capture across institutions has limited their routine use in Canadian post-secondary contexts. Where exposure is unavailable or inconsistently defined, researchers are forced to rely on proxies that collapse heterogeneous participation patterns into uniform denominators. This practice not only limits precision, but also introduces bias when comparing across sports or competitive contexts with fundamentally different exposure structures (Bahr et al., 2020b; Chandran, Morris, et al., 2021).

The consequence of this limitation is a persistent conflation of injury impact with injury risk. Sports that generate a high absolute number of concussions are frequently labeled as high

risk, while those with fewer reported injuries are assumed to be safer. Exposure-adjusted analyses challenge this assumption by demonstrating that sports with lower injury counts may nevertheless have an equal or greater risk of concussion when the number of athlete participations is considered. Such inversion effects are not anomalies; they are predictable outcomes when exposure is explicitly modeled rather than implicitly assumed.

This misclassification has practical implications. Resource allocation, medical staffing, and prevention efforts are often guided by perceived risk derived from unadjusted data. When risk is assessed without accounting for participation volume or opportunities for injury, interventions may be directed toward sports with high visibility or large participation numbers than those in which the likelihood of concussion is greater for each participation. In post-secondary environments with constrained medical resources, this distortion carries tangible consequences for athlete safety and care.

Importantly, exposure misclassification also intersects with sex-based interpretation. Participation patterns differ systematically by sex across many sports, influencing injury counts independent of susceptibility. Without exposure-adjusted analysis, observed sex differences may reflect structural participation inequities rather than biological vulnerability. This interaction reinforces the need to interpret sex and sport risk jointly, rather than as isolated attributes.

Despite broad recognition of these issues within injury epidemiology, exposure-adjusted risk remains underutilized in post-secondary concussion research, particularly within Canadian contexts. This gap reflects not a lack of methodological sophistication, but the absence of standardized exposure definitions and data capture across institutions. Inconsistent tracking of practices, competitions, and training sessions limits the feasibility of standardized exposure

metrics, perpetuating reliance on suboptimal measures (Costello et al., 2024; Ekegren et al., 2016).

Incorporating exposure-adjusted incidence enables differentiation between sports that generate more concussions because athletes are more frequently exposed and those in which each exposure carries a higher probability of injury. This distinction is essential for interpreting concussion risk in a manner that is both epidemiologically sound and operationally meaningful.

Ultimately, the persistence of exposure-unadjusted risk assessment in post-secondary concussion research represents a structural vulnerability in the field. Without consistent exposure data, risk estimation remains contingent on participation patterns rather than injury propensity, limiting the capacity of surveillance systems to inform prevention, policy, and clinical decision-making. Addressing this limitation requires not only analytic adjustment, but systemic commitment to exposure standardization as a core component of concussion surveillance.

Academic Impact as a Measurement Gap in Post-Secondary Concussion Recovery

Recovery from SRC in post-secondary athletes is most commonly operationalized through clinical endpoints, particularly symptom resolution and medical clearance for return to play (Broglio et al., 2014; Patricios et al., 2023). While these indicators are essential, their dominance within concussion surveillance has narrowed the conceptualization of recovery to a medically defined event, often detached from the broader functional context in which post-secondary athletes operate. In academic environments, this narrowing has specific consequences: recovery may be classified as complete despite ongoing educational disruption that remains unmeasured or inconsistently documented.

Academic functioning represents a distinct outcome domain that is structurally embedded within the post-secondary context, yet it is rarely integrated systematically into concussion surveillance. When academic impact is captured, it is often recorded only when formal accommodations are registered, creating a binary representation of a complex and graded process. This approach obscures subclinical or informal academic disruption, including missed instructional time, reduced cognitive load tolerance, or reliance on discretionary flexibility from instructors. The absence of standardized academic metrics therefore limits the ability of surveillance systems to characterize recovery in a manner that reflects the lived demands of post-secondary athletes (Halstead et al., 2013; McAvoy et al., 2020; Pei et al., 2023).

The exclusion of academic outcomes also constrains interpretation of recovery duration. Clinical symptom resolution does not necessarily coincide with restoration of academic functioning, particularly in environments that require sustained cognitive engagement (McAvoy et al., 2020; Sady et al., 2011). Surveillance systems that define recovery solely through medical clearance to return to play implicitly assume equivalence between clinical and functional recovery, an assumption that remains largely untested in post-secondary populations due to measurement absence rather than evidence of equivalence.

This measurement gap has interpretive implications. Studies that report relatively short recovery timelines may do so not because recovery is rapid, but because recovery is narrowly defined (Iverson et al., 2017; Kamins et al., 2017). Conversely, systems that incorporate self-reported academic or cognitive difficulty may report prolonged recovery trajectories that reflect broader outcome capture rather than delayed clinical improvement. Without standardized academic outcome data, comparisons across studies risk conflating true differences in recovery with differences in outcome definition.

Importantly, the omission of academic impact is not a reflection of its irrelevance, but of surveillance design priorities. Clinical surveillance systems are typically oriented toward medical management and RTP decision-making, while academic monitoring falls outside traditional athletic health infrastructure. As a result, academic outcomes become structurally invisible within datasets designed to track injury and clinical care, even when they represent a meaningful component of post-injury experience.

Within this dissertation, academic impact is treated as a missing outcome domain rather than an ancillary consideration. The inability to systematically integrate academic disruption into concussion surveillance limits understanding of recovery completeness and constrains evaluation of institutional support mechanisms. Recognizing academic functioning as a core, though under-measured, dimension of recovery reframes post-secondary concussion not as a purely clinical event, but as an injury with implications that extend into educational systems.

Standardization as a Scientific Prerequisite for Valid Inference in Post-Secondary Concussion Research

Standardization within concussion surveillance is frequently framed as a logistical or administrative objective, intended to improve efficiency, comparability, or reporting compliance across institutions (Bahr et al., 2020b; Finch, 1997b). While these benefits are real, such framing understates the scientific implications of non-standardized data systems. Within the context of this dissertation, standardization of the datasets examined is not merely a matter of logistical convenience; it is a prerequisite for valid inference across studies, institutions, and competitive contexts.

Standardization addresses the problem of non-equivalence. When surveillance systems differ in core variable definitions, outcome domains, temporal resolution, and exposure capture, the resulting data cannot be meaningfully compared without introducing interpretive distortion. Apparent differences between institutions or athlete populations may reflect measurement divergence rather than substantive variation. In the absence of standardization, aggregation becomes analytically hazardous, and synthesis risks compounding rather than resolving uncertainty (Costello et al., 2024; Wilkinson et al., 2016).

This issue is particularly salient in post-secondary sport, where concussion surveillance operates across parallel systems shaped by institutional mandates rather than shared analytic goals. University-based and college-based systems often prioritize different data elements, operate on different temporal scales, and terminate follow-up at different recovery milestones. Each system is internally coherent, yet externally incompatible. Without standardization, attempts to draw national-level conclusions are constrained to the lowest common denominator of available data, effectively discarding meaningful information while preserving bias.

Standardization of the studied datasets does not imply uniformity of surveillance implementation. Rather, it establishes a common analytic language through which diverse systems can communicate. By aligning core constructs, such as injury occurrence, exposure opportunity, recovery milestones, and functional outcomes, standardization enables comparison without erasing contextual nuance. This distinction is critical: standardization facilitates interpretation across systems without requiring identical operational practices at every institution.

From an epidemiologic perspective, the absence of standardized core elements undermines both internal and external validity (Ekegren et al., 2016; Finch, 2006). Internally,

inconsistent variable definitions introduce measurement error that cannot be corrected post hoc. Externally, the inability to align datasets limits generalizability, as findings remain tethered to the idiosyncrasies of individual systems. In this way, non-standardization restricts not only what can be concluded, but also what questions can be credibly posed.

The persistence of non-standardized concussion surveillance also constrains policy evaluation. Interventions, rule changes, and educational initiatives are increasingly implemented across jurisdictions with the expectation of evidence-based assessment. Without standardized data, evaluating the impact of such interventions becomes speculative, as observed changes may reflect shifts in reporting practices rather than true changes in injury patterns. Standardization is therefore essential not only for research synthesis, but for accountability in policy implementation (Bahr et al., 2020b).

Importantly, standardization should be understood as a minimum requirement rather than an aspirational ideal. A minimum data set establishes the foundational elements necessary for interpretability while allowing institutions to collect additional data aligned with local priorities. This approach balances feasibility with rigor, recognizing institutional heterogeneity while safeguarding analytic coherence. Without such a minimum standard, concussion surveillance remains vulnerable to fragmentation that limits cumulative knowledge development.

Within the context of this dissertation, the integration of multiple surveillance systems highlights the need for standardized core data elements across post-secondary concussion surveillance. The integration of baseline, injury, exposure, and functional outcome data demonstrates that interpretive clarity increases when core elements are aligned, even when collected through distinct infrastructures. This alignment does not resolve all sources of uncertainty, but it delineates them, enabling more precise interpretation of observed patterns.

Ultimately, advancing post-secondary concussion surveillance and research requires recognizing elements of standardization as an epistemic necessity. Without shared analytic foundations, the field remains dependent on isolated findings that resist integration, comparison, and translation. Establishing standardized surveillance standards is therefore not an exercise in administrative alignment, but a foundational step toward producing interpretable, comparable, and policy-relevant concussion evidence.

Limitations

The limitations observed across post-secondary concussion research are often treated as study-specific shortcomings to be acknowledged and set aside. However, when considered collectively, the limitations encountered in this dissertation reflect broader structural constraints inherent to existing surveillance systems rather than isolated methodological deficiencies. Treating these limitations as unimportant to post-secondary student-athletes' risks underestimating the true impact of SRC on both health and academic performance. Rather than being peripheral concerns, these surveillance gaps shape what can be understood about concussion within the post-secondary sport environment.

One of the most persistent limitations is the absence of consistently defined exposure data. Without standardized capture of participation opportunity, risk estimation remains contingent on assumptions regarding athlete involvement that cannot be empirically verified. This limitation does not arise from analytic oversight, but from structural variability in how exposure is conceptualized and recorded across institutions. The resulting reliance on unadjusted or partially adjusted metrics exemplifies how surveillance design constrains inference at the most fundamental level. Variability in outcome definition further constrains interpretation. Differences in how recovery endpoints are operationalized, whether through symptom resolution, medical

clearance, or functional benchmarks, introduce heterogeneity that cannot be reconciled through post hoc adjustment. In the absence of standardized outcome constructs, comparisons across systems remain conditional, with observed differences reflecting definitional divergence as much as true variation in recovery.

The limited and inconsistent capture of academic outcomes represents a related structural limitation. Academic disruption is not absent from post-secondary concussion experience, but it is largely absent from surveillance infrastructures designed primarily for clinical management. As a result, datasets may underestimate the functional impact of concussion. This structural invisibility reinforces the central argument that surveillance priorities determine which outcomes are rendered visible and which remain unexamined.

Temporal constraints also shape inference. Retrospective data are subject to recall bias and temporal compression, while prospective systems may truncate follow-up at institutionally defined endpoints. These limitations are often discussed in isolation, yet together they illustrate how surveillance temporality influences observed recovery trajectories. Neither approach is inherently flawed; however, each imposes constraints that must be acknowledged when interpreting results across systems.

Viewed collectively, the limitations encountered are not anomalies but manifestations of a fragmented surveillance system. Their recurrence across studies underscores the need for standardized data elements, consistent exposure capture, and integrated outcome domains. Addressing these limitations requires systemic change rather than incremental analytic refinement, reinforcing the central claim that advancing post-secondary concussion research depends on surveillance reform as much as methodological sophistication.

Surveillance as Infrastructure and the Consequences of Inaction

The analyses presented converge on a central and unavoidable conclusion: the primary barrier to coherent understanding of SRC in post-secondary sport is not a lack of data, nor an absence of clinical expertise, but the structure of the surveillance systems through which concussions are identified and treated. Across baseline assessment, injury documentation, exposure measurement, and outcome capture, surveillance design has been shown to limit interpretability, constrain comparability, and shape the conclusions that can be drawn from data collection efforts.

Within the current surveillance landscape, post-secondary concussion research remains vulnerable to systematic misclassification. Risk is routinely inferred from injury counts rather than exposure-adjusted incidence, recovery is defined by endpoints that prioritize clinical clearance over functional reintegration, and sex-based patterns are interpreted without sufficient attention to measurement context. These practices are predictable outcomes of surveillance systems that were not designed to support integrated inference across institutions or outcome domains.

The persistence of non-standardized surveillance carries tangible scientific costs. Without aligned core data elements, cross-institutional comparison remains unstable, national estimates remain conditional, and synthesis across studies risks conflating methodological divergence with substantive disagreement (Costello et al., 2024; Ekegren et al., 2016). In this environment, apparent inconsistencies in the literature are likely to persist because the field lacks the infrastructure necessary to produce cumulative knowledge.

There are also practical consequences. Institutional decision-making regarding medical staffing, prevention priorities, and academic support is often informed by evidence that lacks exposure normalization or omits functional outcomes (Finch, 2006). When surveillance systems obscure per-exposure risk or render academic disruption invisible, resource allocation may be misaligned with athlete need (Finch, 2006). Over time, this misalignment becomes normalized, reinforcing surveillance practices that reproduce the very uncertainties they purport to resolve.

Importantly, maintaining the status quo does not represent a neutral choice. Continued reliance on fragmented surveillance systems ensures that future research will inherit the same interpretive constraints identified in this dissertation. Incremental analytic sophistication cannot compensate for structural data gaps, and post hoc adjustment cannot recover information that was never collected. Without deliberate alignment of core surveillance elements, advances in concussion science will remain unevenly translatable to post-secondary contexts.

This dissertation demonstrates that greater interpretive clarity emerges when concussion is examined across systems rather than within them. Integrating baseline indicators, injury occurrence, exposure-adjusted risk, and functional outcomes reveals not only patterns of concussion experience, but the conditions under which those patterns become interpretable. Surveillance, when treated as infrastructure rather than administrative afterthought, enables distinction between true variability and measurement artifact.

Advancing post-secondary concussion research therefore requires a shift in emphasis: from isolated study design toward shared analytic foundations. Standardized surveillance does not eliminate uncertainty, but it renders uncertainty intelligible. It allows disagreement to be evaluated rather than assumed, and variability to be contextualized rather than overinterpreted. Without such infrastructure, the field remains constrained by its own measurement architecture.

In this light, the contribution of this dissertation is not limited to the findings of its individual studies. Its central value lies in demonstrating that post-secondary concussion research cannot progress through accumulation alone. Progress depends on the conditions under which data are generated, aligned, and interpreted. Recognizing surveillance as a determinant of knowledge is therefore not a methodological refinement, but a prerequisite for producing evidence that is comparable, interpretable, and capable of informing policy and practice within post-secondary sport.

Conclusion

The three manuscripts comprising this dissertation combined provide insight into the strengths and limitations of concussion surveillance systems and critically appraise the gaps in these systems in the post-secondary athlete population. The diversity in both methods and outcomes reflects the fragmented system in which post-secondary concussion surveillance and research currently operate.

Advancing post-secondary concussion surveillance and research requires more than accumulation of findings. It requires recognition that surveillance architecture shapes inference itself. Until core data elements are standardized and exposure and functional outcomes systematically integrated, the field will continue to mistake measurement divergence for unclear, misaligned, and ill-defined data collection. Ultimately, the findings of this dissertation demonstrate that concussion knowledge in post-secondary sport is determined by the surveillance systems through which injury is observed, measured and interpreted.

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Appendices

Definitions for this appendix:

Tier 1 (Core): Variables that are both feasible to collect at virtually all post-secondary institutions and sufficiently standardized in definition to support cross-institutional aggregation. These represent the minimum dataset required to calculate exposure-adjusted incidence, characterize basic recovery patterns, and report academic impact at the national level.

Tier 2 (Enhanced): Variables that add substantial analytic value but require additional data-collection infrastructure, training, or institutional capacity. These are recommended where feasible and supported by validated tools.

Tier 3 (Supplemental): Variables that depend on advanced infrastructure (e.g., wearable sensors, video review) and are appropriate for institutions with research capacity or specific surveillance priorities.

Feasibility: The practical capacity of an institution to collect a given variable consistently, given existing staffing, training, technology, and administrative resources.

Standardization: The degree to which a variable is defined, measured, and recorded consistently across institutions, enabling meaningful aggregation for population-level analysis.

A variable is included at Tier 1 only when both criteria are satisfied. Variables that are highly standardizable but not broadly feasible (e.g., neurocognitive battery scores) are assigned to higher tiers, as are variables that are easy to collect but difficult to define consistently across settings.

Appendix A. Minimum Data Set (MDS) – Operational Minimum Data Elements for Institutional SRC Surveillance

Domain	Variable	Definition	Format	Tier	Rationale
Athlete & Context	Unique Athlete ID	De-identified, consistent ID across seasons	Alphanumeric (hashed)	1	Enables longitudinal tracking
Athlete & Context	Age at injury	Age in years at SRC	Integer	1	Risk stratification
Athlete & Context	Sex	Roster-designated sex	M/F/Other	1	Sex-specific analyses
Athlete & Context	Sport & Team	Sport, team, division	Categorical/text	1	Stratification
Athlete & Context	Position/Event	Primary playing position or event	Categorical/text	2	Mechanism/risk nuance
Exposure	AE – games	Athlete-exposures in games for period	Integer	1	Incidence denominator
Exposure	AE – practices	Athlete-exposures in practices for period	Integer	2	practice vs game risk
Injury Event	Date/time of injury	Calendar date and time	YYYY-MM-DD hh:mm	1	Temporal analyses
Injury Event	Activity context	Game/practice/other sanctioned	Categorical	1	Context-specific risk
Injury Event	Mechanism	Player-player, equipment, surface, other	Categorical	1	Prevention targeting
Injury Event	Head impact location	Primary impact site	Categorical	2	Mechanism detail
Clinical Course	Initial assessment tool	SCAT version/neurocognitive test	Categorical	2	Diagnostic consistency
Clinical Course	Initial symptom score	SCAT/scale total	Numeric	2	Severity proxy
Clinical Course	Symptom resolution date	Date symptoms resolved	YYYY-MM-DD	2	Recovery metric
Clinical Course	Medical clearance date	Date cleared full RTP	YYYY-MM-DD	1	Primary outcome
Clinical Course	Days to clearance	Injury to clearance interval	Integer (days)	1	Recovery outcome
Academic Impact	Accommodation initiated	Official RTL support started	Yes/No	1	Academic outcome
Academic Impact	Accommodation duration	Number of days supported	Integer (days)	2	Impact measure
Functional Impact	Games missed	Games missed due to SRC	Integer	2	Team impact
Functional Impact	Practices missed	Practices missed due to SRC	Integer	2	Training impact

Data Quality	Completeness flag	Record passes required fields	Yes/No	1	Quality Assurance control
General Well-being	Baseline anxiety screen	Brief self-report of pre-injury anxiety symptoms (e.g., GAD-2)	Numeric (0–6)	2	Contextualizes post-injury symptom interpretation
General Well-being	Baseline depressive symptom screen	Brief self-report of pre-injury depressive symptoms (e.g., PHQ-2)	Numeric (0–6)	2	Contextualizes post-injury symptom interpretation
General Well-being	Baseline general well-being rating	Single-item self-report of overall well-being	Numeric (Likert 1–5)	2	Captures non-specific pre-injury affective state

Appendix A outlines the operational data elements used for institutional sport-related concussion (SRC) surveillance. These variables reflect data that are routinely collected or realistically implementable within university and collegiate sport settings, including variable definitions, formats, and quality control considerations. This appendix emphasizes feasibility and implementation fidelity rather than national standardization.

Appendix B. MDS Tiered Framework

Domain/Variable	Tier 1 (Core)	Tier 2 (Enhanced)	Tier 3 (Supplemental)	Notes
Unique Athlete ID	✓	✓	✓	Pseudo-ID; privacy-preserving hash
Age, Sex, Sport/Team	✓	✓	✓	Core stratifies
Position/Event	-	✓	✓	Risk mechanism detail
AE – games	✓	✓	✓	Minimum denominator
AE – practices		✓	✓	Game vs practice risk
Activity context	✓	✓	✓	Game/practice/other
Mechanism	✓	✓	✓	Player, equipment, surface
Head impact location	-	✓	✓	Optional at Tier 1
Initial assessment tool	-	✓	✓	Standardize SCAT/neurocognitive
Initial symptom score	-	✓	✓	Severity proxy
Clearance date & days	✓	✓	✓	Primary outcome
Symptom resolution date	-	✓	✓	Trajectory metric
RTL accommodation start	✓	✓	✓	Academic outcome
RTL duration	-	✓	✓	Impact measure
Games/Practices missed	-	✓	✓	Impact on team
Wearables/video			✓	Mechanism validation; AE automation
General well-being (anxiety/depression screen)	-	✓	✓	Brief validated screen (ex. GAD-2)

Note. ✓ = Element included at tier. Tier 1 represents the minimum viable dataset required for national comparability and reflects variables that are both feasible across heterogeneous post-secondary institutions and sufficiently standardized in definition to support aggregation. Tier 2 variables expand analytic depth (e.g., severity, recovery trajectory, training-context risk) where institutional capacity permits. Tier 3 variables depend on advanced infrastructure (e.g., wearables, video) and are appropriate for institutions with research capacity. See Appendix A for full definitions of feasibility and standardization.

Appendix B presents a tiered national Minimum Data Set (MDS) framework intended to support harmonized SRC surveillance across Canadian post-secondary sport. Variables are organized into Tier 1 (core), Tier 2 (enhanced), and Tier 3 (supplemental) elements to illustrate scalability across diverse institutional contexts. This framework prioritizes comparability and interoperability rather than operational detail.

Appendix C. Operational to MDS Variable Mapping

Operational Variable (Appendix A)	MDS Domain (Appendix B)	Tier	Notes
Unique Athlete ID	Identification	Tier 1	Persistent linkage
Age at Injury	Demographics	Tier 1	Core stratifiers
Sex	Demographics	Tier 1	Equity analyses
Sport & Team	Sport Context	Tier 1	Benchmarking
Position / Event	Sport Context	Tier 2	Risk nuance
AE – Games	Exposure	Tier 1	Incidence denominator
AE – Practices	Exposure	Tier 2	Context-specific risk
Injury Date / Time	Injury Event	Tier 1	Temporal analyses
Activity Context	Injury Event	Tier 1	Exposure interpretation
Mechanism	Injury Event	Tier 1	Prevention targeting
Head Impact Location	Injury Event	Tier 2	Mechanistic detail
Initial Assessment Tool	Clinical Course	Tier 2	Diagnostic consistency
Initial Symptom Score	Clinical Course	Tier 2	Severity
Symptom Resolution Date	Clinical Course	Tier 2	Recovery trajectory
Medical Clearance Date	Clinical Course	Tier 1	Outcome
Days to Clearance	Clinical Course	Tier 1	Recovery metric
RTL Accommodation Initiated	Academic Impact	Tier 1	Functional outcome
RTL Duration	Academic Impact	Tier 2	Impact
Games / Practices Missed	Functional Impact	Tier 2	Team disruption
Completeness Flag	Data Quality	Tier 1	QA / audit

Appendix C maps operational data elements (**Appendix A**) to their corresponding domains within the proposed national MDS (**Appendix B**). This mapping illustrates how institution-level data collection can be abstracted into standardized national indicators without duplicating variables or increasing reporting concussion symptom severity. Tier 3 variables are not mapped, as this appendix is restricted to data elements currently feasible within institutional surveillance systems.

Appendix D. Minimum Viable MDS (MV – MDS) for National Implementation

Category	Variables
Identification	Athlete ID
Demographics	Age, Sex
Sport Context	Sport, Contact Category
Injury Event	Injury Date, Activity Context, Mechanism
Exposure	Competition AE
Clinical Outcome	Medical Clearance Date, Days to Clearance
Academic Impact	RTL Status, Days Missed from School

Note. The MV-MDS represents the minimum set of variables required to support exposure-adjusted incidence estimation, recovery benchmarking, and academic impact surveillance at a national level.

Appendix D summarizes a Minimum Viable MDS (MV-MDS) representing the smallest set of variables required to support exposure-adjusted incidence estimation, recovery benchmarking, and academic impact surveillance at a national level. This appendix is intended to support policy translation and staged implementation rather than comprehensive research applications.

Appendix E. Evaluation Metrics for Surveillance Performance

KPI	Definition/Target	Frequency	Tier
Data completeness	>=95% required fields per case	Quarterly	1
AE coverage	>=90% of scheduled sessions logged	Monthly	1
Timeliness	>90% cases entered within 7 days	Quarterly	1
Sex/sport stratification	100% institutional reports stratified	Annual	1
Audit pass rate	>=90% institutions meet QA thresholds	Quarterly	2
Interrater reliability	kappa >=0.8 for coding tests	Semi-annual	2
Dashboard utilization	>=75% programs log in monthly	Monthly	2
Policy impact	Documented rule/equipment/education changes	Annual	3

Appendix E outlines the evaluation metrics proposed to assess surveillance system performance across implementation stages. The listed key performance indicators (KPIs) capture core dimensions of system quality, including data completeness, exposure coverage, timeliness, reliability, utilization, and policy impact. This appendix is intended to support phased quality assurance and continuous evaluation of surveillance effectiveness at the institutional and national levels, rather than to function as a direct surveillance dataset.