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Head Injuries from Sports and Recreation Presenting to Emergency Departments in Edmonton, Alberta

by

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Abstract

This thesis investigates head injuries (HIs) occurring in sports and recreation (SR) that presented to emergency departments (EDs) in Edmonton, Alberta, from April 1st, 1997 to March 31st, 2008. There were 4,950 SR HIs identified over the 11 years (5.13 HIs per 1,000 ED injury visits). Individuals less than 18 years old were 3.4 times more likely, and males were 1.25 times more likely to present with a head injury from SR ($p < 0.0001$). A history of one or two previous SR HIs increased the odds of subsequent HI by 2.62 and 5.94 times, respectively, while children aged 7 – 13 and 14 – 17 were more than four times more likely to sustain a HIs from SR ($p < 0.001$). The effects of multiple HIs occurring in children participating in SR activities needs to be addressed, due to the chronic neurobehavioral effects of HIs.

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Table of Contents

Chapter 1 1

Introduction 1

1.1. Overview 1

1.2. Statement of the Problem 1

1.3. Objectives 3

1.4. Significance 3

1.5. References 5

Chapter 2 8

2.1. 8

Review of Literature: Head Injuries 8

2.1.1. Methods 8

2.1.2. Head Injury Definitions 8

2.1.3. Biomechanics of Head Injury 13

2.1.4. Diagnosis of Sport and Recreation Head Injuries 14

2.1.5. Neuroimaging and Neuropsychological Tests 15

2.1.6. Effects of Head Injuries 17

2.1.7. Under-reporting of Sport and Recreation Head Injuries 19

2.1.8. Management of Sport and Recreation Head Injuries and Return to Play Guidelines 21

2.1.9. Summary of Head Injuries 23

2.2. 43

Review of Literature: Head Injuries Occurring in Sports and Recreation Activities 43

2.2.1. Methods.. 43

2.2.2. Review of Literature 43

2.2.3. Contact Sports 43

2.2.4. Collision/Non-Contact Sports 49

2.2.5. Summary of Head Injuries Occurring in Sport and Recreation 59

2.3. 72

Review of Literature: Subsequent Head Injuries from Sports and Recreation . 72

2.3.1. Methods.. 72

2.3.2. Review of Literature 72

2.3.3. Summary of Subsequent Head Injuries from Sport and Recreation 76

2.4. References.. 83

Chapter 3 103

Epidemiology of Sport and Recreation Related Head Injuries Presenting to Emergency Departments 103

3.1. Introduction... 103

3.2. Methods 104

3.3. Results 107

3.4. Discussion... 118

3.5. Conclusion 124

3.6. References 126

Chapter 4 131

Subsequent Head Injuries Occurring from Sports and Recreational Activities 131

4.1. Introduction 131

4.2. Methods 132

4.3. Results 136

4.4. Discussion 144

4.5. Conclusion 149

4.6. References 150

Chapter 5 159

Discussion & Future Directions 159

5.1. Discussion 159

5.2. Methodological Issues 162

5.3. Future Directions 165

5.4. References 169

Appendix A: ACCS SR Activity Codes 181

Appendix B: Sport and Recreation Activity Groupings 185

List of Tables

Table 2.1 Signs and Symptoms of Concussion 11

Table 2.2 Concussion Grading Scales 11

Table 2.3 Glasgow Coma Scale 12

Table 2.4 Graduated Return to Play Protocol 23

Table 2.5 Studies on Sport and Recreation Related Head Injuries 61

Table 2.6 Studies on Sport and Recreation Related Head Injuries 77

Table 3.1 Canadian Emergency Department Triage and Acuity Scale (CTAS). 104

Table 3.2 Rates of Sport and Recreation Related Head Injuries......................... 109

Table 3.3 Rates of Non-Sport and Recreation Related Head Injuries 109

Table 3.4 Head Injuries by Age Group 110

Table 3.5 Frequency of Head Injuries.. 111

Table 3.6 Frequency of Sport and Recreational Head Injuries 112

Table 3.7 Odds Ratio for Males Sustaining a SR Head Injury by Activity 112

Table 3.8 Frequency and Percentage of Triage Codes....................................... 113

Table 3.9 Triage Codes for SR Head Injuries 113

Table 3.10 Disposition After Presenting at Emergency Department.................. 114

Table 3.11 Disposition for SR Head Injuries 114

Table 3.12 Primary Head Injury Diagnosis 115

Table 3.13 Primary Diagnosis of Concussion by Concussion Type................... 116

Table 3.14 Odds of SR Head Injuries with a Documented Primary Procedure.. 117

Table 4.1 Observations Excluded and Remaining 137

Table 4.2 Days Between Head Injuries.. 137

Table 4.3 Cox Proportional Hazard Model: Main Analysis 141

Table 4.4 Cox Proportional Hazard Model: Sensitivity Analysis....................... 142

Table 4.5 Logistic Regression: Odds Ratio for Head Injury from SR Activities 143

List of Figures

Figure 4.1 Kaplan-Meier Time-to-event Fuctions: Estimated Days to SR Head Injury Treated in an Emergency Department.. 138

Figure 4.2 KM Time-to-event Functions by of SR Head Injury Treated in an Emergency Department: Males vs. Females... 139

Figure 4.3 KM Time-to-event Functions by Observed History of SR Head Injury Treated in an Emergency Department:<18 years vs. 18 - 35 years 139

List of Abbreviations

ACCS	-	Ambulatory Care Classification System
ED	-	Emergency department
HI	-	Head Injury
LOA	-	Loss of awareness
LOC	-	Loss of consciousness
MTBI	-	Mild traumatic brain injury
RTP	-	Return-to-play
SR	-	Sports and recreation
TBI	-	Traumatic brain injury

Chapter 1

Introduction

1.1. Overview

There are currently a small number of published Canadian studies that have investigated head injuries (HI) occurring in sport and recreation (SR) activities. This thesis will use population-based data from Edmonton, Alberta, to report and analyze the descriptive epidemiology of SR related head injuries presenting to Emergency Departments (EDs) and the risk of sustaining a subsequent head injury from SR if a history of SR HI exists.

1.2. Statement of the Problem

Every year millions of people participate in sport and recreation (SR) activities. Despite the benefits of participation in physical activity, the nature of many SR activities—competitive or recreational—pose a risk of injury. The severity of injuries seen in SR varies widely, ranging from common contusions and lacerations to rare paralysis or death.

Head injuries (HI) are of particular concern due to the negative effects that head injuries have on cognitive and physical function, the cumulative effects of head injuries,(1-5) and the potential for life-long disability.(4,6) A number of different terms such as traumatic brain injury (TBI), mild traumatic brain injury (MTBI), concussion, head injury (HI), and mild/minor closed head injury have been used to describe head injuries.(7) Epidemiological and clinical research usually refers to head and brain injuries as TBI, MTBI, or head injuries, whereas sports medicine research almost exclusively refers to head and brain injuries as a "concussion". More serious injuries are often referred to as "head trauma" and involve such conditions as epidural, subdural, intra-cerebral bleeds, and skull fractures (compound and closed).

Head injury (HI) will be the term used in this thesis, except when citing definitions and during the literature review, where the terminology used in the original articles will be maintained. This thesis does not investigate the symptoms or effects of head injuries, the methods of diagnosis, or the care/management of head injuries, but a general overview is provided in the literature review.

In the past twenty years, head injuries have generated the most discussion in SR activities. Head injuries commonly occur in SR activities that involve physical contact, such as tackling and body checking; however, head injuries can occur in any sport or recreational activity. In the United States, it is commonly reported that more than 300,000 sport-related head injuries are sustained annually (8); however, this estimate only included head injuries that resulted in a loss of consciousness.(8-10)

Various definitions for head injuries have been published in the literature,(11-15) and partially due to the array of head injury definitions, it is acknowledged that a number of methodological issues exist in head injury research.(8,16) Because a diagnosis of concussion has been previously used when a concomitant loss of consciousness (LOC) has also occurred,(11,17) many head injuries have undoubtedly gone undetected. As it is now widely accepted that a

(LOC) is not required to sustain a concussion, the broader definition of concussion that has emerged over the past twenty years has likely led to an increase in documented SR-related head injuries.

The detrimental effects of head injuries cannot be understated. A number of professional athletes' careers have been plagued or abruptly ended by head injuries. The majority of SR head injury research has focused on professional and elite college and high school athletes, while few population-based studies have investigated head injuries from SR.

1.3. Objectives

The primary objectives of this study are to 1) describe the epidemiology of sport and recreation (SR) related head injuries occurring from April 1st, 1997 to March 31st, 2008 presenting to EDs in the Edmonton, Alberta, Canada, and 2) determine the hazard ratio for presenting to an ED with a SR related head injury if a previous SR related head injury had been observed.

The secondary objectives of this thesis are to 1) determine if the duration between SR related head injuries decreased as the number of head injuries sustained in SR increased, 2) determine which sports and recreational activities significantly increase the odds of sustaining a head injury, when presenting to an ED with a sport or recreation related injury.

1.4. Significance

The significance of this thesis is that limited Canadian population-based studies on SR head injuries currently exist, and moreover, no Canadian studies using population-based data to specifically investigate subsequent head injuries from SR were identified in the literature. Therefore, this thesis will provide clinical-related and community based information on head injuries occurring in sports and recreation activities in a Canadian, population-based sample. Findings that pertain to younger individuals will also contribute to the literature as most SR head injury literature investigates high-school or college aged athletes. Also, this thesis will contribute information to a broad range of sports and recreation activities, rather than the team and contact sports which dominate the SR head injury literature. Subsequent head injuries occurring in SR have been the focus of few published studies; therefore, the results from this thesis will contribute to a growing body of literature that may be used to develop standards for head injury policies in various sports and recreation associations.

There are two studies presented in this thesis; chapter three describes the epidemiology of sport and recreation related HIs presenting to EDs in Edmonton, Alberta; chapter four investigates the risk of sustaining subsequent sport and recreation related HIs for individuals who presented to an ED in Edmonton with a SR injury from April 1st, 1997 to March 31st, 2008.

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Chapter 2

2.1.

Review of Literature: Head Injuries

2.1.1. Methods

Literature was identified by searching Medline, EMBASE, and CINAHL. Search terms used were concussion, head injury, mild traumatic brain injury, traumatic brain injury, sport(s), recreation(al), sport(s) and recreation(al), and ED. Literature was also identified through reference lists of selected articles. Literature focused specifically on head injuries from sports or recreational activities, head injuries, and sports and recreational (SR) activities was given preference.

2.1.2. Head Injury Definitions

A number of terms are used throughout the literature to define a head injury. Terms most commonly used to describe a head injury occurring in sports and recreation (SR) are Traumatic Brain Injury (TBI), Mild Traumatic Brain Injury, Concussion, and Head Injury (HI). A Traumatic Brain Injury (TBI) is defined as being caused by “a bump, blow or jolt to the head or a penetrating head injury that disrupts the normal function of the brain.”(1) TBIs range in severity from mild, inducing no or a brief change in mental status or consciousness, to severe, resulting in a prolonged duration or unconsciousness or amnesia or even death.(1)

Concussions:

Concussions are often discussed when investigating injuries occurring in sport and recreation. A concussion is a variation of a TBI; however, it is usually mild in severity. The terms concussion and mild traumatic brain injury (MTBI) are often used interchangeably to describe head injuries that do not result in death or permanent gross cognitive deficits. A MTBI is defined by the Center for Disease Control and Prevention's (CDC) National Center for Injury Prevention and Control as "*an injury to the head as a result of blunt trauma or acceleration or deceleration forces that result in one or more of the following conditions:*

- *Any period of observed or self-reported:*
  - *Transient confusion, disorientation, or impaired consciousness*
  - *Dysfunction of memory around the time of injury*
  - *Loss of consciousness lasting less than 30 minutes*
- *Observed signs of neurological or neuropsychological dysfunction, such as:*
  - *Seizures acutely following injury to the head*
  - *Among infants and very young children: irritability, lethargy, or vomiting following head injury*
  - *Symptoms among older children and adults such as headache, dizziness, irritability, fatigue or poor concentration, when identified soon after injury, can be used to make the diagnosis of mild TBI, but cannot be used to make the diagnosis in the absence of a loss of consciousness or altered consciousness."*(2)

The most recent and widely accepted definition of a concussion is *"a complex pathophysiological process affecting the brain, induced by traumatic biomechanical force. Several common features that incorporate clinical, pathologic and biomechanical injury constructs that may be utilised in defining the nature of a concussive head injury include:*

> *1. Concussion may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an "impulsive" force transmitted to the head.*
>
> *2. Concussion typically results in the rapid onset of short lived impairment of neurologic function that resolves spontaneously.*
>
> *3. Concussion may result in neuropathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury.*
>
> *4. Concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course.*
>
> *5. Concussion is typically associated with grossly normal structural neuroimaging studies."* (3)

The signs and symptoms of concussions are indicated in Table 2.1.(3) For the majority of individuals who sustain a concussion, most symptoms resolve with a few days or weeks.(4-10) A small percentage of individuals, however, report having symptoms for several months or a few years post-injury.(11-13) The severity of head injuries in SR range widely, which, in turn, has led to numerous

Table 2.1 Signs and Symptoms of Concussion

Cognitive Features	Typical Symptoms	Other Symptoms
Unaware of period, opposition, score of game	Headache	Loss of consciousness/Impaired conscious state
Confusion	Dizziness	Poor coordination or balance
Amnesia (Retrograde and Anterograde)	Nausea/vomiting	Concussive convulsion/Impact seizure
Loss of consciousness	Ataxia/Gait unsteadiness/Loss of balance	Inappropriate playing behaviour (running in the wrong direction)
Unaware of time, date, or place	Feeling “dinged”, stunned, or “dazed”	Slowed/slurred speech or inability/delays in following instructions
	Individual reports having their “bell rung”	Easily distracted/Poor concentration
	Seeing stars or flashing lights	Displaying unusual or inappropriate emotions
	Ringing in the ears	Vacant stare/Glassy eyed
	Blurred or Double vision	Personality changes
		Significantly decreased playing ability

Adapted from: Aubry et al. Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. Recommendations for the improvement of safety and health of athletes who may suffer concussive injuries. Br.J.Sports Med. 2002 Feb;36(1):6-10.

Table 2.2 Concussion Grading Scales

Grading Scale	Grade 1 (mild)	Grade 2 (moderate)	Grade 3 (severe)
American Academy of Neurology (ANN) (14)	No LOC, symptoms < 15 min	No LOC, symptoms > 15 min	LOC
Colorado Medical Society (15)	No LOC, confusion without amnesia	No LOC, confusion with amnesia	LOC
Cantu (16)	No LOC or posttraumatic amnesia < 30 min	LOC < 5 min, posttraumatic amnesia 1-24 hours	LOC > 5 min, posttraumatic amnesia > 24 hours

LOC = Loss of consciousness
From: Adirim. Concussions in Sport and Recreation. Clin Ped Emerg Med. 2007. 8:2-6

grading scales for head injuries, with overlap between the different grades of head injuries (Table 2.2). Because of the redundancy of theses scales, a panel of SR head injury experts recommended abandoning these grading scales.(17)

Head Injuries:

In research pertaining to sports and recreational activities, head injuries have been used to describe TBIs and concussions, while also including skull fractures, facial bone fractures, lacerations, or other injuries occurring anatomically to the head.(18-22) The Glasgow Coma Scale (GCS) is tool commonly used to classify the severity of head injury (Table 2.3).(23,24) Head injuries can range from a minor laceration or bruise to more severe intracranial

Table 2.3 Glasgow Coma Scale

		Score
Eyes Open (E)	Spontaneously	4
	To sound	3
	To pain	2
	No response	1
Best Verbal Response (V)	Oriented	5
	Confused conversation	4
	Inappropriate words	3
	Incomprehensible sounds	2
	None	1
Best Motor Response (M)	Obeys	6
	Localizes pain	5
	Flexion (withdrawal)	4
	Flexion (abnormal)	3
	Extension	2
	None	1
		Total 3 - 15

From: Teasdale G, Jennett B. Assessment and prognosis of coma after head injury. Acta Neurochir. 1976;34(1-4):45-55.

injuries (concussions, TBIs). Clinically, the term head injury (HI) is defined as "an injury that is clinically evident on the physical exam, characterized by ecchymoses, hematoma, lacerations, deformities, or cerebral spinal fluid leakage."(25) A patient with a Glasgow Coma Scale (GCS) score of 3 – 8 is considered to have a severe head injury, while a GCS score of 9 – 12 indicates a moderate head injury, and a GCS score of 13 – 15 indicates a mild head injury.(25)

2.1.3. Biomechanics of Head Injury

Despite the number of definitions for head injuries, the biomechanical principles are similar. Head injuries can be sustained due to a direct blow to the head or an acceleration-deceleration injury due to a blow to the head or forces transmitted to the head from an impact or jolt to elsewhere on the body.(26) A direct blow to the head may result in an injury at the site of impact (so called "coup" injury) or an injury to the brain away from the impact site, resulting from the shaking of the brain within the skull (so called "contrecoup" injury).(26) When both have occurred, a "coup-contrecoup" injury exists. The forces applied from an impact may be linear or rotational and can result in shearing, tensile, and compressive forces on the brain, which can result in a contrecoup injury.(26-28) The injuries sustained due to these biomechanical forces may be focal or diffuse. Focal or localized injuries result in specific injuries and deficits (bruising or laceration to a specific area of the brain), while a diffuse injury affects a broader range of cognitive function as the injury is not localized, and often not obvious on neuroimaging.(26)

It is unclear as to whether linear or rotational forces are better predictors of sustaining a head injury.(27,29,30) While linear forces have been observed to be better predictors of head injuries,(29) another study reported that rotational forces are better predictors of head injury when less than 70% of head injuries are correctly identified.(30) Another study reported no relationship between the location of head impact or the magnitude of linear or rotational impact and acute symptoms, postural stability, or neuropsychological functioning.(27)

The location of the impact to the head has also been investigated as a cause of head injury. Impacts to the top of a football player's helmet have been suggested to result in a higher rate of concussions than impacts to other locations.(27) In a study of head injury impacts in the National Football League,(29) however, despite nearly all head impacts for players initiating a tackle occurring to the top or front of the head, no concussions were reported, while for players who did sustain a concussion (only players being tackled), nearly all of the impacts (against another player or the ground) occurred to the facemask or the side of the helmet. In another study it was reported that 43% of head impacts are to the front of the head while only 13% occur to the top of the head.(30)

2.1.4. Diagnosis of Sport and Recreation Head Injuries

Clinically, head injuries presenting to EDs are assessed by focusing on blunt trauma to the head, skull fractures, LOC, post-traumatic amnesia, seizures, vomiting, headache, Glasgow Coma Score, use of alcohol and medication, and age of patient.(25,31,32) After a patient history and physical examination are performed, patients may be discharged, observed until a normal score on the GCS is observed (reduced symptoms), or admitted to the hospital. All patients with severe head injuries undergo assessment and advanced diagnostic imaging (computerized tomography (CT) scan or magnetic resonance imaging (MRI). Most severe head injuries require hospitalization, some will require surgical intervention, and a small proportion may be fatal. The outcomes general relate to the degree of structural injuries to the brain found on advanced imaging (e.g. MRI or a CT scan).

Many patients with minor head injuries still receive advanced imaging, despite the existence of at least two different adult (31,33) and one pediatric (34) decision aides to guide clinicians on the need for a CT scan. Fortunately, severe head injuries from SR that require surgical intervention are uncommon, as the majority of SR head injuries are less severe, non life-threatening head injuries. Most of the closed/minor head injuries can be discharged, while some will require medical interventions, and a small proportion may return for reassessment.

2.1.5. Neuroimaging and Neuropsychological Tests

There are a number of factors that hinder the detection of head injuries, the first of which is the use of neuroimaging modalities and neuropsychological test batteries to make a definitive diagnosis of head injury. Conventional neuroimaging techniques such as the CT scan and MRI are beneficial for severe head injuries when structural lesions of the brain are suspected; however, these tests do not identify the vast majority of concussions (3,4,35) and are not always readily available. As many as 97% of concussions are not identified through CT scans because the structural brain injuries that are detected by CT scans are not commonly observed in less severe head injuries, such as concussions.(35) Neuroimaging modalities that investigate brain function rather than brain structure, such as positron emission tomography (PET), single photon emission tomography (SPECT), and functional magnetic resonance imaging (fMRI), may have a greater sensitivity to detect milder head injuries (compared to CT scans and MRI)(35-40); however, limited data are available to currently support the use of these modalities.(5,41)

As CT scans and MRIs do not identify the majority of concussions, in the past decade a number of neuropsychological tests have been created to aid with concussion management.(3-5,42-45) The field of neuropsychological testing has been called one of the cornerstones of concussion research.(3,4) Paper-based neuropsychological tests such as the Sport Concussion Assessment Tool (SCAT) and SCAT II,(4,5) the Maddocks Questions,(45) the Standardized Assessment of Concussion (SAC),(44) as well as computer-based tests such as Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) (46) and CogState Sport (47) are used to assess features of cognitive functioning such as motor function, decision making, attention, memory, and information processing.(48) These tests are quick to administer and may last from 5 to 30 minutes. Baseline testing is typically conducted at the beginning of an athletic season and then again after a suspected head injury. Differences between the preseason and post-injury test are used to aid in the assessment of a head injury and whether a cognitive function has returned to baseline measures.

Although neuropsychological tests play an important role, there are limitations to their use. For example, a neuropsychologist is needed to interpret the results for paper based tests, baseline measures are needed, athletes' scores may return to baseline measures while still reporting concussion symptoms, and these tests are subject to practice/learning effects.(44,48-50) The sensitivity and specificity of neuropsychological tests has also been observed to vary between the paper and computer based tests.(48,51,52)

2.1.6. Effects of Head Injuries

The effects of head injuries can be short-term and transient or persistent. Common short-term effects of head injuries are listed above in Table 2.1. Head injuries from SR negatively affect executive thought processes such as processing speed, verbal /visual memory, planning skills, and reaction time (9,12,13,53-59) and are also associated with clinical depression and Alzheimer's disease.(12,13) Suffering from persistent symptoms has been referred to as Post-Concussion Syndrome (PSC). Post-Concussion Syndrome "is characterized by neurological symptoms, such as headache, dizziness, and nausea; emotional disruption, such as depression or irritability; and cognitive deficits including posttraumatic and retrograde amnesia, impaired attention, and slowed mental processing."(60) The symptoms associated with PCS are reported as transient; however, they may be prolonged in some cases and are acknowledged to significantly affect one's quality of life.(60)

Longer-term effects of HI are variable, especially in those where reporting was minimal or nonexistent. Given the common occurrence of SR concussions and minor head injuries, many studies have been performed on former athletes. De Beaumont (57) investigated the effects of concussions on cognitive and motor function 30 years after sustaining a sport related concussion. Former athletes with a history of concussion showed significant reductions on neuropsychological and electrophysiological measures of episodic memory, frontal lobe functions, and speed of motor functions.

In a study of retired National Football League (NFL) players, Guskiewicz et al.(13) observed that the age-adjusted prevalence of Alzheimer's disease is 1.37 (95% confidence interval (CI): 0.98, 1.56) times greater in retired NFL players, compared to the general American male population. A history of multiple concussions was also associated with a physician diagnosis of Mild Cognitive Impairment (MCI) ($p < 0.02$). The prevalence of MCI was 2 times greater for players with 3 or more concussions when compared to players with 1 or 2 previous concussions, while the prevalence of MCI was 5 times greater for those with a history of 3 or more concussions when compared to retirees with no history of concussion.(13)

In another study on retired NFL players,(12) 11.5% of retired players who had sustained 1 or 2 concussions and 31.1% of players with 3 or more concussions perceived the injuries had effected their thinking or memory skills as they aged. Eleven percent of the retired players had been diagnosed with clinical depression. Sustaining multiple concussions was associated with a diagnosis of depression ($p < 0.005$). The prevalence ratio for a diagnosis of depression, compared to those with no concussion history, was 1.5 (95% CI: 1.08, 2.02) for retired players reporting a history of 1 or 2 concussions and 3.06 (95% CI: 2.29, 4.08) for those reporting 3 or more concussions.

More severe effects of head injuries in sport and recreation include permanent and obvious brain damage, as well as death. Second-impact syndrome (SIS) is rare, however is reported to occur when a second head injury is sustained by an individual who has yet to recover from an initial head injury.(61) SIS has been primarily documented in boxers and football players.(61,62)

2.1.7. Under-reporting of Sport and Recreation Head Injuries

Another issue regarding head injuries is that many athletes are not aware they have sustained a head injury.(63-65) In a study on concussion in soccer and football players, Delaney et al.(64) retrospectively surveyed university athletes participating in Canadian Interuniversity Sport (CIS) regarding concussion history and concussion symptoms. A concussion was reported by 13.5% of the soccer players and 6.8% of football players in the previous season; however, 46.2% of soccer players and 34.1% of football players reported experiencing a concussive symptom after a blow to the head, suggesting that only 29% of soccer players and 17% of football players recognized that they had experienced a concussion. The estimated number of concussions sustained for soccer and football players was 1 – 10 and 1 – 13, respectively.

Delaney et al.(63) also retrospectively surveyed players in the Canadian Football League (CFL) regarding concussion history and concussion symptoms. A concussion was reported during the previous season by 8.4% of the athletes; however, 45% reported at least one symptom of a concussion. The authors estimated that 30% of players sustained one concussion, 20% sustained two, 22% sustained three, while 28% (n = 19/69) sustained anywhere from 4 to more than 20 concussions in the 1997 CFL season.

In a second study on the recognition of concussions in CIS soccer and football players,(65) 12.4% of soccer players and 16.5% of football players reported a concussion in the previous season. Again, a large percentage of athletes (62.7% soccer players, 70.4% football players) reported at least one concussive symptom, suggesting that the recognition of concussions among CIS soccer and football players to be only 22% (79 recognized concussion/357 players reporting symptoms).

Along with unrecognized head injuries, some athletes or parents may simply ignore the signs and symptoms of a head injury. Kaut et al.(66) surveyed university athletes entering competitive play from 1995 – 2001 regarding concussion history and post injury behaviour. Twenty-eight percent of the athletes reported continuing to compete in games or practices despite experiencing dizziness after a blow to the head while 19% did not report the symptom while continuing to compete. Continuing to participate despite experiencing a headache after a blow to the head was reported by 30.4%; this, was especially high for football players (61.2%).

SR head injuries also appear to be under-reported in amateur hockey.(67,68) While Goodman et al.(67) suggested that the under reporting of concussions in their study was 50%, others (68) observed that the reported rate of concussion ranged from 14 – 25/Athlete-Exposures (AEs) (though volunteer reports/direct observation) to 40 – 100/AEs (retrospective player survey). There may be a number of reasons as to why recognized head injuries go unreported. A strong desire to compete, pressures from teammates, coaches, parents, and unqualified diagnoses (i.e., no LOC mistakenly considered to mean absence of a HI) may lead to the under-reporting of head injuries.(66,69,70)

2.1.8. Management of Sport and Recreation Head Injuries and Return to Play Guidelines

Another important factor regarding SR head injuries is assessing whether the individual has adequately recovered to participate in SR activities. The ambiguity of when someone should return to SR activities is reflected in more than 20 different concussion management or Return to Play (RTP) guidelines.(71-73) Although RTP guidelines may have increased the awareness of subsequent SR head injuries, the various grading scales and inconsistent management protocols have led to confusion and inconsistent treatment and diagnosis of individuals who have sustained a SR head injury.(74-78) While previous grading scales for SR head injuries did not all require removal from competition, the most recent guidelines for SR head injury require immediate removal from SR activities to assess potential head injuries, the athlete should not be left alone, should be monitored for any deterioration for a few hours post-injury, and evaluated by a physician.(5,17)

In 2001, a panel of leading experts in concussion research developed a consensus statement regarding a definition of concussion as well as a step-wise approach for returning to play/competition and recommended abandoning the current grading scales to classify concussion.(17) The most recent consensus statement from the 3rd International Conference on Concussion in Sport (5) is that the best management of SR head injuries is cognitive and physical rest until the individual is asymptomatic. After the resolution of symptoms, a 6 stage graduated return to play protocol (GRTP) is recommended (Table 2.4).

Each stage is intended to last 24 hours unless symptoms re-emerge, in which case the individual would return to the previous stage for a further 24 hours. A number of issues such as symptoms, signs, sequelae, temporal, threshold, age, pre-morbidities and co-morbidities, medication, behaviours, and sport/activity are acknowledged to act as modifiers that affect the GRTP.(5) As the GRTP guidelines are affected by a number or variables, this should emphasize the importance of individually tailored GRTP programs, rather than a one size fits all approach that had generally been adhered to. However, the reported use of the Graduated Return to Play Protocol is quite low,(79) possibly due to a reluctance to change to a new protocol, especially because none of the return to play guidelines are scientifically validated.

Table 2.4 Graduated Return to Play Protocol

Stage	Functional exercise	Objective
1. No Activity	Complete physical and cognitive rest	Recovery
2. Light aerobic exercise	Walking, swimming, or stationary cycling keeping intensity at < 70% maximum predicted heart rate No resistance training	Increase heart rate
3. Sport-specific exercise	Skating drills in hockey, running drills in soccer No head impact activities	Add movement
4. Non-contact training drills	Progression to more complex training drills (eg. passing drills in football and hockey) May start progressive resistance training	Exercise, coordination, and cognitive load
5. Full contact practice	Following medical clearance participate in normal training activities	Restore confidence and assess functional skills by coaching staff
6. Return to play	Normal game play	

From: McCrory et al. Consensus Statement on Concussion in Sport: the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. Br.J.Sports Med. 2009 May;43 Suppl 1:i76-90.

In a study on compliance with RTP advice, Ackery et al.(70) observed that 33% (5/15) of hockey players did not follow return to play advice (discontinue all contact spots) due to *"perceived pressure from their team, self-assumed recovery and readiness to play, and because they 'missed playing the game"*, while 25% of players (2/8) who were allowed to return to contact sports returned earlier than advised.

2.1.9. Summary of Head Injuries

Despite the majority of head injury symptoms typically resolving within a few days or weeks post injury,(4-10) sustaining subsequent head injuries may have long term consequences.(57) With the acceptance of a more inclusive definition of concussion developed by a panel of SR head injury experts,(3) the reported incidence is likely to increase. Head injuries may continue to go unrecognized, however, if the awareness of head injury signs, symptoms, and outcomes do not increase. The perception that head injuries are ‘minor’ or disregarded entirely if not a result of a direct impact to the head, or do not result in severe symptoms or a loss of consciousness, will continue to place individuals at risk of subsequent head injuries.

Accurately identifying and managing head injuries that occur in SR activities can be challenging. Medical advice and recommendations for the management of SR head injuries by physicians and other professionals vary.(74,79,80) With no implemented “gold” standard for clinical management of SR head injury or return-to-play criteria,(79,80) individuals who suffer a head injury may have a greater risk for future SR related head injuries because treatment regimes vary widely. In the broader population, it is often a parent/guardian or the athlete themselves who make the decision of when to return to play. It is, however, recommended that all athletes who sustain a head injury in SR, regardless of their skill level, should be managed using the same treatment and RTP guidelines.(5)

2.2.

Review of Literature: Head Injuries Occurring in Sports and Recreation Activities

2.2.1. Methods

Literature was identified by searching Medline, EMBASE, and CINAHL. Search terms used were concussion, head injury(ies), mild traumatic brain injury, traumatic brain injury, sport(s), recreation(al), sport(s) and recreation(al), and ED. Literature was also identified through reference lists of selected articles. Literature focused specifically on head injuries from SR was given preference.

2.2.2. Review of Literature

The occurrence of injury in sports and recreational activities is well documented. Research on head injuries from SR has primarily focused on the sports of football, hockey, and soccer. Although the sport of boxing has demonstrated considerable frequency of head injuries,(81) boxing is not included in the literature review, as boxing is difficult to compare other SR activities where the primary goal is not to knock-out an opponent. A number of head injury studies from a variety of SR activities, as well as population based studies are discussed below.

2.2.3. Contact Sports

Hockey

Hockey is an extremely popular sport in many countries, especially Canada. Hockey also has some of the highest rates of head injuries at both the amateur and professional levels. In a four year study of professional hockey players in Sweden, Tegner & Lorentzon (82) reported that 22% of the players reported suffering a combined total of 87 previous concussions throughout their careers. Six percent of all prospectively identified injuries (52/805) were concussions. Nine percent of the prospectively followed players suffered at least one concussion.

Recently in North America, head injuries in the National Hockey League (NHL) have generated considerable discussion. Reviewing media reports from the 1997/1998 – 2007/2008 seasons, Wennberg & Tator (83) reported that the rate of concussions ranged from 1.04/1,000 Athletic-Exposures (AEs) (2005/2006 season) to 1.81/1,000 AEs (1998/1999 season). The average rate of concussions was 1.45/1,000 AEs over the 10 NHL seasons. The mean number of concussions sustained per season was 68.8 (688 concussions over 10 years). A test for trend showed the average number of reported concussions significantly decreased over the 10 seasons ($p = 0.01$).

Higher rates of head injury in hockey have also been reported in women's collegiate hockey in the United States. Using data from the NCAA ISS for the 2000/2001 – 2003/2004 seasons, Agel et al.(84) reported that 21.6% of in game injuries and 13.2% of injuries during practices were a concussion. The rate of concussions sustained in games was 2.72/1000 AEs (95% CI: 2.02, 3.43). Injuries to the head and neck accounted for 25.4% of in game injuries and 16.2% of injuries occurring in practices.

In men's collegiate hockey, the percentage and rate of in game concussions has been reported to be lower than in female's hockey. From the 1988/1989 – 2003/2004 seasons, Agel et al.(85) reported that concussions accounted for 9% (n = 422) of in game injuries and 5.3% (n = 105) of injuries during practices. The rate of in game concussions was 1.47/1,000 AE (95% CI: 1.33, 1.61). Injuries to the head and neck accounted for 15.4% of in game injuries and 10.3% of injuries occurring in practices.

Head injuries also commonly occur in minor hockey. Body checking in minor hockey has been identified as a major contributor to head injuries,(86) however, the age at which body checking is introduced in minor hockey varies (typically in pee wee/11 – 12 year olds or bantam/13 – 14 year olds). In the United States, Gerberich et al.(69) retrospectively surveyed varsity high school hockey players at the conclusion of the 1982/1983 season. Although a concussion was defined only as a loss of consciousness or a loss of awareness, concussions still accounted for 12% of all injuries. Injuries to the head and neck accounted for 22% of all reported injuries.

In a prospective study of minor hockey players in Calgary, Alberta (87) the investigators examined hockey injuries during the 2004/2005 season. Concussions accounted for 18% of injuries. The rate of concussion for Atom (9-10 years of age), Pee Wee (11-12), Bantam (13-14), and Midget (15-16) hockey players was 0.24, 0.81, 0.97, and 0.82 per 1,000 AE, respectively.

In another study of hockey players in Canada, Goodman et al.(67) prospectively investigated head injuries in the British Columbia Junior Hockey League for the 1998/1999 and 1999/2000 seasons. For the 1998/1999 season, 10.66% of players were identified to have a concussion resulting in an in game concussions rate of 5.98/1,000 player-game hours. During the 1999/2000 season, 7.42% of players were identified to have sustained a concussion. The rate of concussions occurring in games for the 1999/2000 season was 4.63/1,000 player-game hours.

Although head injuries are commonly reported in hockey, it should be noted that rates of head injury in hockey have been shown to widely vary based on the reporting technique. In a study on minor hockey players in British Columbia (68) investigators explored these variations using four different techniques. A retrospective review of official injury reports with the hockey league indicated the rate of concussions was 0.35/1,000 player-game hours for the 2003/2004 season. Prospective reports from team volunteers for the 2002/2003 season indicated a concussion rate of 5.70/1,000 player-game hours, while retrospective surveys of elite players from 2001 - 2003 indicated a concussion rate of 7.39/1,000 player-game hours, and retrospective surveys of non-elite players in 2004 indicated a concussion rate of 16.20/1,000 player-game hours.

Football

Head injuries in football occur frequently due to the amount of player contact, and at least 497 fatalities due to head injuries in football have been reported in the United States from 1945 – 1999.(88) Rates of head injury vary by the level of play (89) but are reported to range from 0.50 to 2.34/1,000 AEs.

In American high school football, a study of head injuries sustained during the 1977 season, (90) reported that concussions (diagnosed concussions, LOC & LOA) accounted for 24% of all injuries, while a LOC was reported by 14% of all players. The rate of concussion was 19/100 players. Recently, Zemper (91) prospectively followed American high school and college football players over a two year period. The rate of concussion in high school football during the 1997 and 1998 football seasons was 0.50/1,000 AEs, while the rate of concussions for college players was 0.57/1,000 AEs. The combined rate of concussion was 0.54/1,000 AEs. Concussions accounted for nearly 10% of all injuries, while 4% of the athletes sustained a concussion.

In another study of American high school and college football players, Guskiewicz et al.(89) reported that 5% of players sustained a concussion and the overall rate of concussion was 0.70/1,000 AEs, or 1.28/1,000 contact-AEs (actual plays), from 1995 – 1997. When stratified by level of play, high school players had the highest rate of concussions (1.03/1,000 AEs, 1.63/1,000 contact-AEs) while division 1 college players had the lowest (0.49/1,000 AEs, 0.94/1,000 contact-AEs). High school players and division 3 college players sustained a significantly higher proportion of concussions than college players in division 1 and 2.

At the college level, a considerably higher rate of head injury was reported by Dick et al.(92) by using the NCAA's injury surveillance system. From the 1988/1989 – 2002/2003 seasons, the rate of concussions occurring in games was 2.34/1,000 AE (95% CI: 2.24, 2.44). Concussions accounted for 6.8% (n = 2,085) of in game injuries, while 5.6% (n = 612) and 5.5% (n = 2,319) of injuries occurring in practices, for the spring and fall seasons respectively, were concussions.

Although few studies on professional football players in North America exist, professional football players have a high rate of head injury. In a prospective study of head injuries occurring in the National Football League (NFL), Pellman et al.(93) reported 787 concussions occurring in NFL games from 1996 – 2001. The average rate of concussion per season was 131.2 (SD = 26.8), while the head injury rate was 0.40 concussions/game.

Rugby

High rates of head injuries have also been reported in rugby; however, the highest rates are reported within the lower levels of rugby. From 2005 – 2006, Collins et al.(8) observed that the most commonly injured body region in American high school rugby players was the head (21.7%). Concussions accounted for 15.8% of injuries. A similar proportion of concussions were observed for males and females (16.1% vs. 14.3%). In Australia from 2005 - 2007, Hollis et al.(94) reported that the rate of MTBI in non-professional rugby players was 7.97/1,000 player-game hours (95% CI: 6.94, 9.11). A MTBI was sustained by 9.8% (n = 313) of the 3,207 players. For players less than 21 years of age the incidence ratio for MTBI was 10.54/1,000 player-game hours (95% CI: 8.34, 13.13). At the professional level, Kemp et al.(7) reported the rate of concussions occurring in rugby games was 4.1/1,000 player-hours (95% CI: 3.3, 5.0), with 8% of injuries observed identified as concussions.

2.2.4. Collision/Non-Contact Sports

Soccer

Worldwide, soccer is the most popular sport. Although soccer is not a contact sport (i.e., body checking and tackling are not allowed) head injuries are frequently reported. At the high school level, a study by Yard et al (6) from 2005 – 2007 reported concussions accounted for 10.8% of soccer related injuries.(6) A greater proportion of females' injuries were concussions (12.2% vs. 9.3%), but were not significantly greater.

Although the percentage of concussions occurring at the collegiate level is lower than those reported for high school soccer players, collegiate female soccer players sustain concussions more frequently and a higher proportion of females' injuries are concussions. From the 1988/1989 to 2002/2003 seasons, Agel et al (95) reported that the rate of concussion occurring in games for men's soccer was 1.08/1,000 AE (95% CI: 0.98, 1.19), while Dick et al.(96) reported that the rate of concussions for females was 1.42/1,000 AEs (95% CI: 1.29, 1.55). Concussions accounted for 5.8% and 8.6% of injuries occurring in games, and 1.8% and 2.2% of injuries occurring in practices for males and females, respectively.(95,96)

Head injuries in soccer are not limited to elite high school and college athletes. Using data from the United States Consumer Product Safety Commission's (CPSC) National Electronic Injury Surveillance System (NEISS), Leininger et al.(97) reported that concussions accounted for 2% (n = 830) of soccer related injuries seen in American EDs from 1990 – 2003 for children 2 – 18 years of age. Nationally, it was estimated that 30,286 (1.9%) of soccer-related injuries were concussions. Although males were more likely to sustain an injury to the head or neck (RR = 1.40; 95% CI: 1.32, 1.49), similar proportions of males and females sustained a concussion (2.0% vs. 1.7%). In Canada, concussions have been observed to account for 14% (n = 33) of soccer related head injuries seen in EDs for persons aged 10 – 24.(18)

Lacrosse

Reported rates of head injuries in lacrosse are lower than sports such as hockey, but head injuries still commonly occur. At the high school level, concussions have been observed to account for 72.8% and 39.5% of injuries to the head for boys and girls, respectively.(98) The rate of concussions for high school athletes was similar for males and females; 0.28/1,000 AEs for boys and 0.21/1,000 AEs for girls. At the college level, the rate of concussions in college lacrosse ranges from 0.37/1,000 AEs to 1.08/1,000 AEs for males and 0.32/1,000 AEs to 0.70/1,000 AEs for females.(98-100) The proportion of concussions sustained in collegiate lacrosse both games and practices is slightly higher for females than males (games, 9.8% vs. 8.6%; practices, 4.6% vs. 3.6%).(99,100)

Basketball

Like the sports of soccer and lacrosse, basketball does not allow tackling or excessive body contact, yet head injuries are commonly reported. For the 1988/1989 – 2003/2004 seasons, Dick et al.(101) reported that the rate of concussions in men's collegiate basketball was 0.32/1,000 AEs (95% CI: 0.27, 0.37) and accounted for 3.6% (n = 151) of injuries occurring in games and 3.0% (n = 236) of injuries occurring in practices. In Canada, a similar percentage of concussions has been reported in men's university basketball (3.7%),(102) and the reported rate of concussions was 0.16/1,000 AEs. Despite a similar proportion of concussions sustained, the rate of concussions reported in men's university basketball in Canada is half the rate reported in the United States (0.16/1,000 AEs vs. 0.32/1,000 AEs).

Similar to differences in male and female collegiate soccer players in the United States, the rate of concussion for female basketball players and the proportion of concussions sustained are higher for females than males. In women's basketball, Agel et al.(103) reported that the rate of concussions occurring in games was 0.50/1,000 AEs (95% CI: 0.43, 0.56), while concussions accounted for 6.5% (n = 230) of injuries occurring in games and 3.7% (n = 245) of injuries occurring in practices. The percentage of in game concussions for females is nearly twice that of males (6.5% vs. 3.6%), however females and males have similar proportions of concussions occurring during practices (3.7% vs. 3.0%).(101,103)

Baseball & Softball

Although the rate of head injuries occurring in baseball and softball are much lower than other team sports, the overall proportion of concussions sustained is similar to those observed for basketball. From 1988/1989 – 2003/2004 Dick et al.(104) reported that the rate of concussions during men's collegiate baseball was 0.19/1,000 AEs (95% CI: 0.16, 0.22), and concussions accounted for 3.3% (n = 148) of injuries occurring in games and 1.6% (n = 62) of injuries occurring in practices. The rate and proportion of concussions sustained by females were higher than those for males. Marshall et al.(105) reported that the rate of concussions occurring in games was 0.25/1,000 AEs (95% CI: 0.21, 0.29), and concussions accounted for 6% (n = 151) of game injuries and 2.8% (n = 77) of injuries in practices. Females sustained nearly double the proportion of concussions as males in games (6% vs. 3.3%) and practices (2.8% vs. 1.6%).(104,105)

Skiing, Snowboarding, Sledding

Skiing, snowboarding, and tobogganing/sledding are popular winter activities in northern countries. Among skiers and snowboarders, Wasden et al.(106) reported that injuries to the head account for 20.4% and 27% of injuries, respectively, with 42% of these injuries being classified as an intracranial injury. Furthermore, traumatic brain injuries at ski resorts in the United States have been observed to account for 45.6% of the fatalities, (107) with significantly more children ($\leq$ 17 years of age) sustaining fatal TBIs than adults (66.7% vs. 42.2%; p = 0.05).

Similar to ski and snowboard injuries in the United States, the proportion of head injuries sustained from skiing and snowboarding in Canada is also quite high. In Alberta, McBeth et al.(108) reviewed ski and snowboard injuries from 1996 – 2006 using data from the Southern Alberta Trauma Registry. Brain injuries were observed to account for 52% of injuries with an Injury Severity Score greater than 12, while 80% (n = 4/5) of the fatalities were a result of a TBI.

In Canada and the United States, 4 – 58% of sledding related injuries have been identified as concussions or closed head injuries.(109-111) Head injuries from sledding also account for a high proportion of sledding injuries for young children (56% 0 – 4 years, 41% 5 – 9 year olds),(109) while children 2 – 6 years of age are reported to be 2.6 times more likely (95% CI: 1.46, 4.64) to sustain a head or neck injury than children 7 – 18 years of age ($p < 0.001$).

Equestrian

Although equestrian activities may not be typically thought of as major contributor to SR head injuries, head injuries from equestrian activities account for a greater proportion of all injuries than other SR activities.(112) Head injuries from equestrian activities may also be more severe than other SR activities as 12% of equestrian related head injuries require admission to hospital with 23% of admitted cases due to a head injury.(113) For equestrian related injuries treated in EDs, TBIs account for 12.4% of injuries, with 16% of children less than 18 years of age sustaining a TBI and 10% of individuals 18 years and older sustaining a

TBI.(114) Females were significantly more likely to sustain a TBI in equestrian related activities than males (13.4% vs. 10.4%; p = 0.002).(114)

Cycling

Cycling is a common recreational activity, as well as a major cause of SR head injury.(19,112) Head injuries from cycling may largely be due to collisions with vehicles or other objects involving high rates of speed, or simply due to the way in which a fall of collision occurs. Reviewing 16 years of data from the National Electronic Injury Surveillance System (NEISS) in the United States, Mehan et al.(115) reported that 14% of injuries were injuries to the head, and 2% of injuries (n = 3,403) were concussions. Despite the relatively low proportion of concussions recorded, head injuries accounted for 45% of bicycle related fatalities. The average age of children sustaining an injury while cycling was 9.7 years (SD = 3.9). Intracranial injuries accounted for 96% of injuries that occurred to an internal organ, and were 5.84 times more likely (95% CI: 4.9, 6.97) to require hospitalization.

Off-Highway Vehicles (OHVs)

The use of Off-highway vehicles is popular in many regions of Canada and the United States. Injuries from these vehicles are often severe. In the United States, Fonseca et al.(116) retrospectively reviewed data for patients were admitted to hospital due to motorcycle and All-Terrain Vehicle (ATV) collisions between January 1998 and August 2004. Of the 573 patients admitted to hospital 61% (n = 352) were due to the use of motorcycles and 39% (n = 221) were due to

ATVs. Closed head injuries accounted for 54% of ATV injuries and 45% of motorcycle injuries. A significantly lower proportion of ATV users had worn helmets while operating their ATVs compared to those operating motor cycles (9% vs. 65%, $p < 0.001$). In Canada, Yanchar et al.(117) reported that head injuries accounted for 10% of ATV injuries that presented an ED from January 1st, 1993 – December 31st, 2002.

Recreational Activities

While a substantial number of ED visits occur annually in Canada and the United States, a large percentage of these SR related injuries are attributed to general recreation and leisure activities. In Canada, Cunningham et al.(75) reported that 21.3% (n = 20) of minor head injuries presenting to EDs in Kingston, Ontario were attributed to leisure and recreation, while Thurman et al (118) reported 49% (n = 105,241) of SR related TBIs seen in American EDs are from general recreation activities. In Australia, Browne & Lam (74) reported that 74.3% (n = 440) of children presenting to EDs with a concussive head injury were due to non-organized SR activities, while Crowe et al.(21) observed that 31.8% (n = 129) of head injuries were attributed to sport and recreation, while an additional 17.2% (n = 70) of head injuries were attributed to leisure activity.

Although 17% - 74% of SR related head injuries that are treated in EDs are due to general recreation and leisure activities, a few SR activities account for the majority of SR head injuries in Canada, Australia, and the United States. In Edmonton, Alberta, Kelly et al.(19) reported that six SR activities (hockey (21%), cycling (13%), playground equipment (8%), soccer (7%), football (5%), and rugby (5%)) accounted for nearly 60% of head injuries. Although head injuries accounted for only 3% of SR injuries presenting to EDs, head injuries from SR accounted for 24% of all head injuries seen in EDs.(19)

In Australia, Crowe et al.(21) reported that head injuries were sustained in 18 different SR activities, with head injuries most commonly seen in Australian-Rules football (33.3%), cricket (12.4%), equestrian (11.6%), basketball (9.3%), soccer (8.5%), and hockey (5.4%). In the United States, the Centers for Disease Control and Prevention (112) reported that TBIs were most frequently observed for the SR activities of cycling, football, playground activities, basketball, and riding all-terrain vehicles. The CDC also reported that TBIs accounted for more than 7.5% of all injuries seen from the SR activities of horseback riding (11.7%), ice skating (10.4%), riding ATVs (8.4%), tobogganing/sledding (8.3%), and bicycling (7.7%).

Sex and Age Differences

Sex-differences also affect head injuries occurring in sports and recreation. For instance, although males commonly sustain a greater percentage of SR head injuries than females, females may be more likely to sustain a head injury from comparable SR activities such as soccer, basketball, and baseball/softball.(119,120) While elite male soccer players have been reported to be 1.42 to 2.16 times more likely to sustain a head injury in soccer,(121,122) findings from other studies challenge these finding.

In a six year prospective study of international soccer players, Fuller et al.(123) reported that the incidence of concussion was 2.4 times greater in females than males. In American high school athletes, Powell & Barber-Foos (120) reported that females have higher rates of MTBIs in sports like soccer (0.23 vs. 0.18/ 1,000 AEs), basketball (0.16 vs. 0.11/1,000 AEs), and baseball/softball (0.10 vs. 0.05/1,000 AEs). Darrow et al,(119) reported that male high school athletes had a higher rate of severe injury than females (0.45 vs. 0.26/1,000 AEs), yet among comparable activities (soccer, basketball, baseball/softball), the rate of severe injury was 1.28 times higher for females (95% CI: 1.08, 1.52; $p = 0.006$). Their national estimates for the proportion of concussion occurring in for girls were higher for basketball (6.6% vs. 1.2%) and all girls' sports (6.7% vs. 5.7%), while males sustained a greater percentage of concussion in soccer (11.8% vs. 7.7%) and baseball/softball (1.4% vs. 1.2%). While at the college level, Delaney reported that females were 2.6 times more likely to sustain a concussion than males ($p = 0.004$).(65)

Regardless of SR activity, population based studies do not support an increased risk of head injury for females. A study in Calgary, Alberta, reported that female high school students were 21% less likely (OR = 0.79; 95% CI: 0.58, 1.06) to sustain a concussion than males,(124) while other population based studies have reported that males sustain 71% - 78% of SR head injuries.(19,21,74) Kelly et al.(19) reported that the rates of SR head injury were significantly higher ($p < 0.05$) for males aged 10 – 14 (25.3/10,000 population vs. 8.8/10,000 population), 15 – 19 (31.5 vs. 11), and 20 – 24 years of age (5.7 vs. 2.1). In the

United States, males are reported to account for 70.5% of SR related head injuries treated in EDs.(112) Rates of SR head injury were greatest for males and females aged 15 – 24 (10/100,000 population vs. 3.1/100,000), 5 – 14 (7.5/100,000 vs. 2.5/100,000), and 25 – 34 (3.8/100,000 vs. 1.6/100,000), respectively.

Even higher proportions of head injuries are sustained by males when investigating younger age groups. In Australia, Crowe et al.(21) observed that males 6 – 16 years of age accounted for 77.5% of the SR head injuries seen in EDs, while from 2000 - 2004, Yang et al.(125) estimated that males account for 83.7% of hospitalized SR related concussions annually in the United States for children 5 – 18 years of age.

While the proportion of males and females who sustain SR head injuries varies by activity, rates of head injury also vary by age group. In the United States, the rates of SR head injury have been reported as 10/100,000 population and 3.1/100,000 for males and females aged 15 – 24, 7.5/100,000 and 2.5/100,000 for those 5 – 14 years of age, and 3.8/100,000 and 1.6/100,000 for those 25 – 34 years of age, respectively.(118) Within younger populations and specific SR activities, rates of head injuries are even higher. Using data from the United States Consumer Product Safety Commission (CPSC) to investigate hospital treated injuries occurring from informal recreation, Baker et al.(126) reported that the highest rate of head injury was for children aged 1 – 4 (149/100,000 people), followed by those aged 5 – 14 (97/100,000), and 15 – 24 years old (5/100,000). However, even higher rates of head injury have been reported by the CDC in the

United States,(112) where those 10 – 14 and 15 – 19 years of age were estimated to each have approximately 350 head injuries /100,000 people.

In Canada, younger populations have also been reported to have higher rates of head injury from SR and account for the majority of SR head injuries. Research in Alberta(19) has indicated higher rates of SR head injury for younger males and females aged 10 – 14 (25.3/10,000 persons; 8.8/10,000 persons), as well as those 15 – 19 years of age (31.5/10,000; 11/10,000), compared to males and females aged 20 – 34 (5.7/10,000; 2.1/10,000), respectively. Also, 66% of SR head injuries occurred for individuals less than 20 years of age.

2.2.5. Summary of Head Injuries Occurring in Sport and Recreation

The majority of research on SR head injuries has focused on elite competitive athletes who have the greatest exposure to SR head injuries. Head injuries are not limited to competitive or even contact sports, and occur frequently. The proportion of head injuries varies by activity, and has been reported to range from 2% of children's cycling injuries to 54% of ATV injuries.(115,116) The highest rates of head injuries are reported in hockey, football, rugby, and soccer (7,67,68,83-85,87,89-96); however, a greater proportion of head injuries occurring from equestrian activities, cycling, off-highway vehicles, and skiing/snowboarding maybe severe or fatal head injuries.(106,108,109,113-117)

Although males are believed to have higher rates of head injury than females, this varies by activity.(124) While females are reported to have higher rates of severe injuries for comparable activities such as soccer, basketball, and baseball/ softball, (119-122,124) often gender comparisons for head injuries are either not made or not statistically significant.(120,124) In population-based studies using ED or hospitalization data, research has identified that a high percentage of head injuries that occur for males (19,21,74) and for individuals 9 – 18 years of age, are due to SR activities.(19,20,112) Individuals who do not reach elite levels of competition or who participate strictly in recreational or leisure activities are still at risk of head injury due to participation in sports and recreation.

Table 2.5 Studies on Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings: Rates, ORs, RRs	Main Head Injury Findings: Head Injuries
Emery & Messuwisse (87)	2004/05	Prospective Cohort	Minor hockey players (8 – 17 year olds), Calgary, Alberta	Concussion	**Rate**: 0.24/1,000 AE (95% CI: 0.05, 0.70) (Atom), 0.81/1,000 AE (95% CI: 0.43, 1.39) (Pee Wee), 0.97/1,000 AE (95% CI: 0.57, 1.55) (Bantam), 0.82/1,000 AE (95% CI: 0.51, 1.25) (Midget). **Relative Risk (vs. Atom Division):** RR = 3.4 (95% CI:0.93, 18.61) (Pee Wee), RR = 4.04 (95% CI: 1.17, 21.54) (Bantam), RR = 3.41 (95% CI: 1.02, 17.87) (Midget)	**Head injuries: 18%** **Injuries to the head/neck:** 20%
Williamson & Goodman (68)	2002 - 2004	Descriptive Epidemiological: retrospective review of official league injury reports, prospective observation (volunteer reports), retrospective survey of players	Minor hockey players, British Columbia	Concussion	**Rate:** 0.35/1,000 PGH (official reports), 5.70/1,000 PGH (volunteer reports), 7.39/1,000 PGH (retrospective survey—Elite players), 16.20/1,000 PGH (retrospective survey—Non-elite players)	**Head Injuries:** 60 (official reports), 22 (volunteer reports), 79 (retrospective survey—Elite players), 26 (retrospective survey—Non-elite players)
Gerberich et al. (69)	1982 – 1983	Descriptive Epidemiological: Retrospective survey	High school varsity hockey players, USA	Concussion	**Odds Ratio:** OR = 1.8 (95% CI: 0.65, 4.7) if previous history of LOC	**Head injuries:** 12% **Injuries to the head/neck:** 22%

Table 2.5 (Continued) Studies on Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings	
					Rates, ORs, RRs	Head Injuries
Goodman et al. (67)	1998/99 – 1999/00	Prospective cohort	Junior 'A' hockey players, British Columbia	Concussion	**Rate:** 5.98/1,000 PGH(98/99); 4.63/1,000 PGH (99/00)	**Head injuries:** 10.66% (1998/99 season), 7.42% (99/00)
Zemper (91)	1997 – 1998	Prospective cohort	Male high school and colligate football players, USA	Concussion	**Rate**: 0.54/1,000 AE (all); 0.50/1,000 AE (high school); 0.57/1,000 AE (college) **Relative Risk:** RR (all) = 5.8 (95% CI: 4.8, 6.8); RR (high school athlete) = 6.6 (95% CI: 5.0, 8.8); RR (college athlete) = 5.3 (95% CI: 4.3, 6.6)	**Head Injuries:** 10% (n = 572; 240 high school, 332 college)
Dick et al. (92)	1988/89 - 2003/04	Descriptive Epidemiological: Retrospective review of injury Surveillance System	Male Collegiate Football players (Div 1 - 3), USA	Concussion	**Rate**: 2.34/1,000 AE (95% CI: 2.24, 2.44) (Fall game); 0.21/1,000 AE (95% CI: 0.20, 0.22) (Fall practices); 0.54/1,000 AE (95% CI: 0.50, 0.58) (Spring practices)	**Head injuries:** 6.8% (games), 5.5% (Fall season practices), 5.6% (Spring season practices) Injuries to the head/neck: 11.5% (Fall games), 10.1% (Fall practices), 9.8% (Spring practices)
Guskiewicz et al. (127)	1999 – 2001	Prospective Cohort	Male collegiate football players (Div 1 – 3), USA	Concussion	**Rate:** 0.81/1,000 AEs (95% CI: 0.70, 0.93)	**Head Injuries:** 196
Pellman et al.(128)	1996 – 2001	Prospective cohort	Professional football players (National Football League), USA	MTBI /Concussion		**Head Injuries:** 887

Table 2.5 (Continued) Studies on Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings	
					Rates, ORs, RRs	Head Injuries
Pellman et al.(93)	1996 – 2001	Prospective cohort	Professional football players (National Football League, USA	Concussion/ MTBI	**Rate:** 0.41/game; 131.2 (SD = 26.8)/year	**Head Injuries:** 787
Collins et al. (8)	2005 – 2006	Descriptive Epidemiological: Retrospective review of injury Surveillance System	Male and female high school rugby players, USA	Concussion		**Head injuries:** 15.8%; 16.1% male, 14.3% female
Hollis et al. (94)	2005 - 2007	Prospective cohort	Non-professional rugby players, Australia	MTBI/Concussion	**Rate:** 7.97/1,000 PGH	**Head Injuries:** 347 (9.8% of athletes)
Kemp et al. (7)	2002/03 - 2005/06	Prospective Cohort Study	Professional male rugby players, English Premiership rugby union clubs	Concussion	**Rate:** 4.1/1,000 Player hours (95% CI: 3.3,3.5)(matches); 0.02/1,000 (95% CI: 0.01, 0.04)(training)	**Head injuries:** 92% (none), 7% (one), 1% (two); 10% were a subsequent concussion
Leininger et al. (97)	1990 – 2003	Descriptive Epidemiological: retrospective review of national injury surveillance system	2 – 18 year old soccer players, USA	Concussion	**Relative Risk (head/neck injury):** RR(boys) = 1.40; 95% CI: 1.32,1.49; RR(children 2 – 4)= 2.65; 95% CI: 2.09,3.36)	**Head injuries:** 1.9% Injuries to the head/neck: 7.98%
Pickett et al. (18)	1996 - 2001	Descriptive Epidemiological: retrospective review of injury surveillance system	10 - 24 year old soccer players, Kingston, Ontario	Head Injury		**Head Injuries:** 14% concussions, 16.2% minor closed head injuries, 9.8% fractures Injuries to the head: 13.7%

Table 2.5 (Continued) Studies on Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings: Rates, ORs, RRs	Main Head Injury Findings: Head Injuries
Yard et al. (6)	2005/06 - 2006/07	Descriptive Epidemiological: retrospective review of injury surveillance system	Male and female high school soccer players, USA	Concussion		**Head Injuries:** 10.8%; 9.3% male, 12.2% female Injuries to the head: 13.7%; 13.1% male, 14.6% female
Agel et al. (95)	1988/89 - 2002/03	Descriptive Epidemiological: Retrospective review of injury Surveillance System	Male Collegiate Soccer Players (Div 1 - 3), USA	Concussion	**Rate:** 1.08/1,000 AE (95% CI: 0.98, 1.19) (game); 0.08/1,000 AE (95% CI: 0.06, 0.09) (practice)	**Head injuries:** 5.8%(games); 1.8%(practices)
Dick et al. (96)	1988/89 - 2002/03	Descriptive Epidemiological: Retrospective review of injury Surveillance System	Female Collegiate Soccer players (Div 1 - 3), USA	Concussion	**Rate:** 1.42/1,000 AE (95% CI: 1.29, 1.55) (games); 0.12/1,000 AE (95% CI: 0.10, 0.14) (practices)	**Head injuries:** 8.6% (games), 2.2% (practices) **Injuries to the head/neck:** 13.8% (games), 3.9% (practices)
Lincoln et al. (98)	2000 - 2003	Descriptive Epidemiological: Prospective observation of injury surveillance systems	High school and college lacrosse players, USA	Concussion	**Rate:** 0.28/1,000 AEs high school boys; 0.21/1,000 AEs high school girls; 0.37/1,000 AEs college males; 0.32/1,000 AEs college females	**Injuries to the head (concussions):** 72.8% boys, 39.5% girls (high school); 84.8% males, 41.4% females (college)
Dick et al. (100)	1988/89 - 2003/04	Descriptive Epidemiological: Retrospective review of injury Surveillance System	Male Collegiate Lacrosse players (Div 1 - 3), USA	Concussion	**Rate:** 1.08/1,000 AE (95% CI: 0.92, 1.25) (games); 0.12/1,000 AE (95% CI: 0.10, 0.14) (practices)	**Head injuries:** 8.6% (games), 3.6% (practices) **Injuries to the head/neck:** 11.7% (games), 6.2% (practices)
Dick et al. (99)	1988/89 - 2003/04	Descriptive Epidemiological: Retrospective review of injury Surveillance System	Female Collegiate Lacrosse players (Div 1 - 3), USA	Concussion	**Rate:** 0.70/1,000 AE (95% CI: 0.57, 0.84) (games); 0.15/1,000 AE (95% CI: 0.12, 0.18) (practices)	**Head injuries:** 9.8% (games), 4.6% (practices) **Injuries to the head/neck:** 21.9% (games), 12% (practices)

Table 2.5 (Continued) Studies on Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings	
					Rates, ORs, RRs	Head Injuries
Dick et al. (101)	1988/89 - 2003/04	Descriptive Epidemiological: Retrospective review of injury Surveillance System	Male Collegiate Basketball players (Div 1 - 3), USA	Concussion	**Rate:** 0.32/1,000 AE (95% CI: 0.27, 0.37) (games); 0.12/1,000 AE (95% CI: 0.10, 0.13) (practices)	**Head injuries:** 3.6% (games), 3.0% (practices) **Injuries to the head/neck:** 13.9% (games), 11.2% (practices)
Meeuwisse et al. (102)	2 years	Prospective cohort study	Male university basketball players, Canada	Concussion	**Rate:** 0.16/1,000 AE	**Head injuries:** 4.19%
Agel et al. (103)	1988/89 - 2003/04	Descriptive Epidemiological: Retrospective review of injury Surveillance System	Female Collegiate Basketball Players (Div 1 - 3), USA	Concussion	**Rate:** 0.50/1,000 AE (95% CI: 0.43, 0.56) (game); 0.15/1,000 AE (95% CI: 0.13, 0.17)(practice)	**Head injuries:** 6.5%(games); 3.7%(practices)
Dick et al. (104)	1988/89 - 2003/04	Descriptive Epidemiological: Retrospective review of injury Surveillance System	Male Collegiate Baseball players (Div 1 - 3), USA	Concussion	**Rate**: 0.19/1,000 AE (95% CI: 0.16, 0.22) (games); 0.03/1,000 AE (95% CI: 0.02, 0.04) (practices)	**Head injuries:** 3.3% (games), 1.6% (practices) **Injuries to the head/neck**: 9.0% (games), 6.6% (practices)
Marshall et al. (105)	1988/89 - 2003/04	Descriptive Epidemiological: retrospective review of injury Surveillance System	Female collegiate softball players (Div 1 - 3),USA	Concussion	**Rate:** 0.25/1,000 AE (95% CI: 0.21, 0.29) (games); 0.07/1,000 AE (95% CI: 0.06, 0.09) (practices)	**Head injuries:** 6.0% (games), 2.8% (practices) **Injuries to the head/neck:** 13.4% (games), 9.6% (practices)
Fonseca et al. (116)	1998 – 2004	Descriptive Epidemiological: retrospective review of ED data	All Terrain Vehicle (ATV) injuries, USA	Closed Head Injury		**Head injuries:** 48.5% (n = 278); 44.9% motorcycles , 54.9% ATVs

Table 2.5 (Continued) Studies on Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings	
					Rates, ORs, RRs	**Head Injuries**
Yanchar et al. (117)	1993 - 2002	Descriptive Epidemiological: retrospective review of ED data in a national surveillance system	All-Terrain Vehicle (ATV) injuries, Halifax, Nova Scotia	Head Injury		**Head Injuries:** 10% **Injuries to the head/neck:**26.1%
Mehan et al. (115)	1990 – 2005	Descriptive Epidemiological: retrospective review of national injury surveillance system	Children's (≤ 18 yrs) bicycle injuries in the general population, USA	Concussion	**Relative Risk:** RR(hospitalization) = 3.63 (95% CI: 3.22, 4.10); RR(death) = 5.77 (95% CI: 2.56,12.98)	**Head injuries:** 2% concussion
Cuenca et al. (113)	11 years	Descriptive Epidemiological: retrospective review of ED data	Children (≤ 18) with equestrian injuries, USA	Head Injury		**Head injuries:** 20% **Activity Type:** 82% recreational, 12% competitive/supervised events, 6% other
Loder (114)	2002 - 2004	Descriptive Epidemiological: retrospective review of national injury surveillance system	Equestrian related injuries in the general population presenting to an ED, USA	Traumatic Brain Injury		**Head Injuries:** 12.4%; 16.4% <18 years, 10.4% ≥ 18; 13.4% male, 10.4% female **Activity:** 30.4% at sporting/recreation facility **Injuries to the head/neck:**23.8%

Table 2.5 (Continued) Studies on Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings	
					Rates, ORs, RRs	**Head Injuries**
McBeth et al. (108)	1996 – 2006	Descriptive Epidemiological: retrospective review of ED data	Ski and snowboard injuries, Alberta (southern)	Traumatic Brain Injury		**Head Injuries:** 2.6% (n = 196) **Activity:** 56.6% skiing, 43.4% snowboarding **Sex:** 81.6% male, 18.4% female **Age (mean):** 30.8 (SD = 14.6) (range, 15 - 80) (overall); male 31.5 (SD = 14.9), female 27.4 (SD = 12.7)
Ortega et al. (110)	1993 - 1997	Descriptive Epidemiological: prospective observation with telephone/mail follow-up	Children's sledding injuries, USA	Head Injury / Closed Head Injury	**Relative Risk (head/neck):** RR(age 2 – 6) = 2.6 (95% CI: 1.46, 4.64)	**Head Injuries:** 12% (n = 20) **Injuries to the head/neck:** 53.6%; 75% $\leq$ 6, 45% 7 – 18
Skarbek-Borowska et al. (109)	2001/02	Descriptive Epidemiological: retrospective review of national injury surveillance system	Children's sledding injuries, USA	Traumatic Brain Injury		**Head Injuries:** 9% TBI; 58% concussion, 42% internal injury **Injuries to the head/neck:** 56% (0-4 yrs), 41% (5-9), 24% (10-14), 19% (15-19)
Voaklander et al. (111)	1997 - 1999	Descriptive Epidemiological: retrospective review of ED data and follow-up survey	Sledding injuries in the general population, Edmonton, Alberta	Head Injury		**Head Injuries:** 4% concussion, 36.6% fractures **Injuries to the head:** 13%
Wasden et al. (106)	2001/02 – 2005/06	Retrospective Cohort	Ski and snowboard injuries, USA	Head Injury		**Head Injuries:** 7.1% concussion; 6.42% skiing, 8.62% snowboarding **Injuries to the head:** 22.5%;20.4% Skiing, 27.3% snowboarding

Table 2.5 (Continued) Studies on Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings: Rates, ORs, RRs	Main Head Injury Findings: Head Injuries
Loder (129)	2002 – 2004	Descriptive Epidemiological: retrospective review of national injury surveillance system	Children's playground equipment Injuries, USA	Traumatic Brain Injury		**Head injuries:** 8.5% (n = 1,539); Female = 7.5%, Male = 9.9% **Activity:** Monkey bars (7%), slides (8.2%), swings (11.9%) **Injuries to the head/neck:** 30.7% **Age (mean):** 6.5 (SD = 3.0)
Baker et al. (126)	1991	Descriptive Epidemiological: Retrospective review of national injury surveillance system	0 – 24 year olds with injuries from informal recreation, USA	Head Injury	**Rate:** 149/100,000 persons (aged 1 – 4); 97/100,000 (age 5 – 14)	**Head injuries:** 13%; 21% (<5 yrs), 11% (5 – 14), 5% (15 – 24) **Activities Associated with head injuries:** Playground equipment (15%); Children's vehicles (20%); Skateboards & roller-skates (6%)
Browne & Lam (74)	2000 – 2003	Case Series; Retrospective chart review	6 – 16 year olds with sport and leisure injuries, Australia	Concussive Head Injury/ Concussion	**Odds Ratio:** OR(organized sport) = 4.54 (95% CI: 2.30, 8.94) for children over 10 years old vs. children less than 10 years old; OR (severe concussion)= 5.57 (95% CI: 1.30, 23.81) if occurring in organized sport vs. recreation OR (RTP instructions)= 0.36 (95% CI: 0.18, 0.70) if occurring in organized sport vs. recreation	**Head injuries:** 71.6% male, 28.4% female; 3% (age 0 – 4), 45.6% (5 – 9), 51.4% (10 - 16) **Activity Type:** Organized sport (25.7%), other physical activities (74.3%) **Severity:** Mild concussion (71%), moderate concussion (25.1%), severe concussion (3.2%)

Table 2.5 (Continued) Studies on Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings	
					Rates, ORs, RRs	Head Injuries
Centers for Disease Control and Prevention (CDC) (112)	2001 - 2005	Descriptive Epidemiological: retrospective review of national injury surveillance system	MTBIs due to sport and recreation activities in the general population, USA	Traumatic Brain Injury		**Head injuries:** 5.1% annually (n = 207,830); 70.5% male, 29.5% female; 5.6% (5 – 18 years); **Activity :** TBI most frequently seen due to cycling, football, playground activities, basketball, ATVs
Crowe et al. (21)	2004	Descriptive Epidemiological: retrospective review of ED data	School aged children (6 – 16 years old) with head injuries from SR, Australia	Head Injury		**Head injuries:** 31.8% Sport and recreation, 17.2% leisure activities **Activity Type:** Head injury most frequently seen due to Australian-Rules football (33.3%), cricket (12.4%), equestrian (11.6%), basketball (9.3%), soccer (8.5%), and hockey (5.4%)
Crowe et al. (20)	2004	Descriptive Epidemiological: retrospective ED chart review	Pediatric head injuries (0 – 16 year olds), Australia	Head Injury		**Head injuries:** 7.2% (0 – 2 years), 21% (3 – 5), 38.1% (6 – 8), 45.9% (9 – 11), 54.1% (12 – 14), and 47.3% (15 – 16)
Cunningham et al. (75)	2005 - 2006	Prospective case series: Presentation to an ED with a minor head injury	General population with minor head injury, Kingston, Ontario	Minor head injury		**Head injuries:** 41.5% Sport and physical recreation, 21.3% leisure and recreation
Kelly et al. (19)	1996/97	Descriptive Epidemiological: retrospective review of ED data	Sport and recreation injuries in the general population, Edmonton, Alberta	Head Injury		**Head injuries**: 3%; 66% < 20 years of age **Activity:** 60% of SR head injuries due to hockey, cycling, playground equipment, soccer, football, rugby

Table 2.5 (Continued) Studies on Sport and Recreation Related Head Injuries

Study	**Study Year(s)**	**Study Design**	**Target Population**	**Head Injury Term**	**Main Head Injury Findings**	
					Rates, ORs, RRs	**Head Injuries**
MacKellar (130)	1986 - 1987	Descriptive Epidemiological: Prospective observation	Pediatric head injuries presenting to an ED, Australia	Head Injury		**Head injuries:** 11% concussion, 4% skull fracture **Activity::** 52% play, 16% recreation, 8% cycling, 4.8% organized sport
Yang et al. (125)	2000 – 2004	Descriptive Epidemiological: retrospective review of all-payer inpatient care database	5 – 18 year olds admitted to hospital with a primary diagnosis of SR related TBI in the general population, USA	TBI /Concussion	**Odds Ratio (hospitalized):** OR(male) = 1.14 (0.87, 1.49); OR(10-14 years) = 1.91 (1.34, 2.71)(vs. 5-9); OR(15-18 years) = 2.28 (1.64, 3.18)(vs. 5-9)	**Head Injuries:** 1,568; 87.3% male, 12.7% females; 50.3% 15 – 18 years of age **LOC:** 40.8% no LOC, 38.9% brief LOC, 12.6% LOC unspecified duration **Procedures (principle):** 81.1% none, 12.3% imaging (59.4% CT scan, 10.5% MRI)
Powell & Barber-Foss (120)	1995 – 1997	Observational Cohort	Male and female American high school athletes	Mild Traumatic Brain Injury	**Rates (Males):** Baseball: 0.05/1,000 AE (95% CI: 0.02, 0.07); Basketball: 0.11/1,000 AE (95% CI: 0.08, 0.15); Soccer: 0.18/1,000 AE (95% CI: 0.14, 0.22) **Rates (Females):** Softball: 0.10/1,000 AE (95% CI: 0.06, 0.14); Basketball: 0.16/1,000 AE (95% CI: 0.12, 0.21); Soccer: 0.23/1,000 AE (95% CI: 0.18, 0.28)	**MTBIs (Males):** Baseball: 1.7%; Basketball: 2.6%; Soccer: 3.9% **MTBIs (Females):** Softball: 2.7%; Basketball: 3.6%; Soccer: 4.3%

Table 2.5 (Continued) Studies on Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings: Rates, ORs, RRs	Main Head Injury Findings: Head Injuries
Boden (122)	1995 - 1996	Prospective Cohort	American Collegiate Soccer players	Concussion	**Rates:** 0.6/1,000 AE (males), 0.4/1,000 AE (females) Ratio of Concussions: 1.42 males : 1 female	**Head injuries:** 17 males, 12 females
Barnes (121)	1993	Retrospective Survey with telephone follow-up	Elite male and female soccer players	Concussion	**Rates:** 0.6/1,000 AE (males), 0.4/1,000 AE (females) Ratio of Concussions: 1.42 males : 1 female **Odds ratio(males):** 2.16	**Head injuries:** 64 males, 28 females
Fuller (123)	1998 – 2004	Case-Control	Male and Female International Soccer players	Concussion/ Head injury	**Rates (head and neck):** 12.8/1,000 PGH (males), 11.5/1,000 PGH (females)	**Head injuries:** 16 males, 12 females
Darrow (119)	2005 – 2007	Descriptive Epidemiological: Retrospective review of injury Surveillance System	Male and Females High school sport injuries	Concussion	**Rates (Males):** Baseball: 0.19/1,000; Basketball: 0.24/1,000 AE; Soccer: 0.25/1,000 AE **Rates (Females):** Softball: 0.18/1,000 AE; Basketball: 0.34/1,000 AE; Soccer: 0.33/1,000 AE	**Head injuries (Males):** Baseball: 1.4%; Basketball: 1.2%; Soccer: 11.8%; All Sports: 5.7% **Head injuries (Females):** Softball: 1.2%; Basketball: 6.6%; Soccer: 7.7%; All Sports: 6.7%

2.3.

Review of Literature: Subsequent Head Injuries from Sports and Recreation

2.3.1. Methods

Literature was identified by searching Medline, EMBASE, and CINAHL. Search terms used were *subsequent*, *recurrent*, and *multiple*, combined with *concussion*, *head injury*, *mild traumatic brain injury*, and *traumatic brain injury*. Literature was also identified through reference lists of selected articles. Literature that focused specifically on head injuries from SR activities was given preference.

2.3.2. Review of Literature

The awareness and concern over concussions has dramatically increased in the past twenty years. It is reported that an athlete who suffers a head injury is at greater risk of sustaining a subsequent head injury than those with no previous head injury.(65,91,127) A number of studies have investigated subsequent head injuries in high school, college, and professional athletes.(7,13,63-65,69,89-91,94,102,127,128,131-133)

An increased risk for sustaining a subsequent head injury has been shown to exist for individuals with a previous history of head injury, and may increase the risk of a subsequent head injury by 1.4 – 11.1 times.(63-65,69,89-91,102,127,131) In two early studies of high school hockey and football injuries, athletes with a previously reported LOC were 1.8 and more than 4 times more likely to sustain subsequent head injuries, respectively, than players without a previous LOC.(69,90) Recently, in a two year prospective study in the United

States,(91) high school football players who had sustained a concussion in the previous 5 years were 6.6 times more likely (95% CI: 5.0, 8.8) to sustain a concussion than players without a previous concussion.

In an Australia study, 9.3% of amateur rugby players sustained a subsequent MTBI in one season.(94) The rate of MTBI for players who had sustained a MTBI in the previous 3 months was more than 2.5 times greater than the rate for players with no recent MTBI (16.99/1,000 Player-Game Hours (PGH) (95% CI: 9.26, 28.58) vs. 6.55/1,000 PGH (95% CI: 5.52, 7.71)). The rate of MTBI for players reporting 2 or more MTBI in the 12 months prior to entering the study was nearly three times greater than players with no MTBI 12 months prior to entering the study (18.80/1,000 PGH (95% CI: 13.36, 25.71) vs. 6.33/1,000 PGH).

Within American college football, players in the United States have been reported to be 1.4 to 5.3 times more likely to sustain a subsequent concussion if they have sustained a concussion in the previous 5 – 7 years,(91,127) while players reporting 2 or 3 previous concussions are 2.5 and 3.0 times more likely to suffer a subsequent concussion, respectively.(127)

In Canada, the rate of concussions for university football players with a previous concussion is reported to be 71% greater than that for players with no previous concussion (1.50/1,000 AEs vs. 0.88/1,000 AEs).(131) Football players with previous concussions are 1.63 to 4.2 times more likely to sustain a subsequent concussion than those without a history of concussions.(64,65,131)

An increased risk of concussion has also been observed in collision/non-contact sports in Canada. Two studies involving university athletes have reported that soccer players who have previously sustained a concussion are 3.15 to 11.12 times more likely to sustain a subsequent concussion than soccer players who have not sustained a previous concussion,(64,65) while men's basketball players are reported to be 4 times more likely (95% CI; 1.11, 14.37) to sustain a concussion if a previous history of concussion exists.(102)

Subsequent head injuries have also been investigated in professional football and rugby players. In the United States, a study on repeat concussions in the National Football League (NFL) (128) observed that 650 players reported 887 MTBI—of which 24.6% of players (n = 160) sustained multiple concussions within the 6 year study. Of the 160 players with subsequent concussions, 68% sustained 2 concussions, 22.5% sustained 3, and 9% sustained 4 – 7 concussions. The median duration between a first and second concussion was 374.5 days. In the Canadian Football League (CFL), Delaney et al.(63) reported that players with a previous LOC while playing football were 6.15 times more likely to sustain a subsequent concussion, while those who reported a previously recognized concussion during football were 5.10 times more likely to sustain a subsequent concussion. In professional rugby, Kemp et al.(7) observed that 10% of concussions sustained over 3 seasons were subsequent head injuries.

As well as an increased risk of subsequent head injury, a few studies have also reported that a 1% to 24%, of subsequent concussions within the same season,(7,89,127) and the average number of concussions experienced by Canadian university athletes in a 12 month period is nearly three.(133) Within American high school athletes, Swenson et al.(132) estimated that concussions account for 11.6% of recurrent injuries nationally, with the sports of football, boys' and girls' soccer, girls' basketball, wrestling, baseball, and softball, all reporting a greater proportion of subsequent concussions than new concussions.

While 4% - 5% of American high school and college football players sustain a concussion within a single season,(89,91) Guskiewicz et al.(89) reported that 14.7% of these players sustained a subsequent concussion, suggesting players with a history of concussion are three times more likely to have a subsequent concussion in the same athletic season. When stratified by level of play, 17% of high school athletes, 9.8% of division 1 college players, 24% of division 2 players, and 11.8% of division 3 players sustained subsequent concussions. However, contrary to these findings in football, Kemp et al.(7) observed that only 1% of concussions sustained in a professional rugby league were subsequent concussions within the same season.

In a study of Canadian university athletes in Quebec, Bloom et al.(133) 51% (n = 170) of athletes reported sustaining at least one concussion in the previous year, while the average number of concussions experienced by athletes in the previous 12 months was three (males = 3.39, females = 2.58). Although the number of recognized concussions sustained did not significantly differ, males recognized less concussion than females (10.6% vs. 17.1%; $p < 0.05$). Overall, males sustained significantly more concussions than females ($p < 0.05$).

2.3.3. Summary of Subsequent Head Injuries from Sport and Recreation

An increased risk for sustaining a subsequent head injury has been shown to exist for individuals with a previous history of head injury, and may increase the risk of a subsequent head injury by 1.4 – 11.1 times.(63-65,69,89-91,102,127,131) Also, multiple head injuries within the same season have been reported to range from 1% to 24%,(7,89,127) while the average number of concussions experienced in a 12 month period has been reported to be three.(133)

While subsequent head injuries from SR have been investigated from high school to professional athletes, no studies were identified that investigated subsequent SR head injuries within a Canadian population-based sample. The majority of SR head injury research has focused on populations with the greatest exposure to head injuries, elite competitive athletes; however, some of these cohorts are managed closely by an entire medical team, which is rarely seen in youth sports and recreational activities.

Table 2.6 Studies on Sport and Recreation Related Head Injuries

Study	**Study Year(s)**	**Study Design**	**Target Population**	**Head Injury Term**	**Main Head Injury Findings**	
					Rates, ORs, RRs	**Head Injuries**
Gerberich et al. (69)	1982 - 1983	Descriptive Epidemiological: retrospective survey	High school varsity hockey players, USA	Concussion	**Odds Ratio:** OR = 1.8 (95% CI: 0.65, 4.7) if previous history of HI existed	
Gerberich et al. (90)	1977	Descriptive Epidemiological: retrospective survey	High school varsity football players, USA	Concussion		**Previous LOC:** 14% (1 previous LOC), 3% (2 previous LOC), 1% (3 previous LOC); **Subsequent Head Injuries:** 40% of 112 players who sustained a LOC had a previous LOC; Players were more than 4 times likely to sustain a subsequent LOC if a history of LOC existed
Guskiewicz et al. (89)	1995 - 1997	Prospective cohort	Male high school and collegiate football players, USA	Concussion		**Subsequent Head Injuries:** 14.7% (131) (all players); 17% (58) high school, 11.8% (22) division 3 college, 24% (27) division 2 college, 9.8% (24) division 1 college
Zemper (91)	1997 - 1998	Prospective cohort	High school and collegiate football players, USA	Concussion	**Relative Risk:** RR (all) = 5.8 (95% CI: 4.8, 6.8) RR (high school athlete) = 6.6 (95% CI: 5.0, 8.8) RR (college athlete) = 5.3 (95% CI: 4.3, 6.6)	**Head injuries:** 10% (240 high school athletes, 332 college athletes)

Table 2.6 (Continued) Studies on Subsequent Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings: Rates, ORs, RRs	Main Head Injury Findings: Head Injuries
Guskiewicz et al. (127)	1999 - 2001	Prospective cohort study	Male collegiate football players, USA	Concussion	**Rate:** 0.81/1,000 AE (95% CI: 0.70, 0.93) (all) 0.96/1,000 AE (95% CI: 0.66, 1.25) (1 previous HI) 1.85/1,000 AE (95% CI: 0.91, 2.79) (2 previous HI) 2.23/1,000 AE (95% CI: 0.85, 3.63) (3 or more HI)	**Head Injuries:** 196 **Subsequent Head Injuries:** 35.1% **Severity:** 14.8% grade 1, 69.8% grade 2, 15.4% grade 3
Hagel (131)	1993 - 1997	Prospective cohort	Male university football players, Canada	Concussion	**Rate:** 1.50/1,000 AE if previous history of HI **Rate Ratio (adjusted):** RR = 1.63 (95% CI: 1.07, 2.50)	
Pellman et al. (128)	1996 - 2001	Prospective cohort study	Professional football players (NFL), USA	MTBI /Concussion		**Head Injuries:** 650 players sustained 887 HI; 160 (24.6%) had repeat HI, 51 (7.9%) had 3 or more HI; 75.6% (one HI), 16.8% (two), 5.6% (three), 1.2% (four), 1.1% (five – seven) **Duration between HI (median):** 374.5 days between 1st and 2nd HI (range, 0 – 1,693); 38 HI within 90 days of initial injury (median duration = 31.5 days); Duration time first and second HI (mean) = 1.05 years; time between second and third HI (mean) = 1.20 years

Table 2.6 (Continued) Studies on Subsequent Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings: Rates, ORs, RRs	Main Head Injury Findings: Head Injuries
Delaney et al. (63)	1998	Descriptive Epidemiological: retrospective survey	Professional football players (CFL), Canada	Concussion	**Odds Ratio:** OR = 6.15 ($p < 0.05$) if previous LOC during football; OR = 5.10 if previous recognized concussion during football; OR = 1.66 if previous LOC not during football	**Recognized Head Injury:** 8.4% **Reported a sign/symptom:** 44.8% **Previously Head Injuries (mean):** 2.0 (SD = 1.6)
Delaney et al. (64)	1998	Descriptive Epidemiological: retrospective survey	Male and female university soccer and male university football players, Canada	Concussion	**Odds Ratio:** OR = 11.12 if previously recognized concussion from soccer; OR = 1.67 if previously recognized concussion not during soccer; OR = 3.83 if previously recognized concussion during football; OR = 7.14 if previous LOC not during football; OR = 4.20 if previously recognized concussion not during football	**Recognized Head Injuries:** 13.5% soccer players, 6.8% football players **Reported a sign/symptom:** 46.2% soccer players, 34.1% football players **Estimated Head Injuries:** 1 – 10 soccer players, 1 – 13 football players

Table 2.6 (Continued) Studies on Subsequent Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings	
					Rates, ORs, RRs	**Head Injuries**
Delaney et al. (65)	1999	Descriptive Epidemiological: retrospective survey	Male and female university soccer and male university football players, Canada	Concussion	**Odds Ratio:** OR = 2.60 if Female (soccer); OR = 3.15 if previous recognized HI in soccer; OR = 8.02 if previously recognized HI not in soccer; OR = 0.74 if previous LOC during soccer; OR = 0.65 if previous LOC not during soccer; OR = 1.94 if previous recognized HI during football; OR = 3.09 if previous recognized HI not during football; OR = 2.44 if previous LOC during football; OR = 2.95 if previous LOC not during football	**Recognized concussion:** 12.4% soccer players, 16.5% football players **Reported a sign/symptom:** 62.7% soccer players, 70.4% football players

Table 2.6 (Continued) Studies on Subsequent Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings	
					Rates, ORs, RRs	Head Injuries
Hollis (94)	2005 - 2007	Prospective cohort	Non-professional rugby players, Australia	MTBI /Concussion	**Rate:** 8.94/1,000 PGH (95% CI: 5.60, 13.56) (1 HI 12 months prior to study); 18.80/1,000 PGH (95% CI: 13.36, 25.71) (≥ 2 HI 12 months prior to study); 6.55/1,000 PGH (95% CI:5.52, 7.71) (HI 12 months prior to study); 12.54/1,000 PGH (95% CI:9.26, 28.58) (HI 6 - 12 months prior); 12.76/1,000 PGH (95% CI: 4.02, 30.00) (HI 3 - 6 months prior); 6.99/1,000 PGH (95% CI:8.51, 17.80) (HI < 3 months prior); **Incidence Ratio (<21 years old):** 10.54/1,000 PGH (95% CI: 8.34, 13.13)	**Head Injuries:** 313 players sustained 347 HI
Kemp et al. (7)	2002/03 - 2005/06	Prospective cohort study	Professional male rugby players, English Premiership Rugby Union clubs	Concussion		**Head Injuries:** 7% (one), 1% (two); 10% were a subsequent HI **Severity:** Subsequent HI sustained in the same season were more severe than the first (22 days lost vs. 12 days lost)

Table 2.6 (Continued) Studies on Subsequent Sport and Recreation Related Head Injuries

Study	Study Year(s)	Study Design	Target Population	Head Injury Term	Main Head Injury Findings	
					Rates, ORs, RRs	Head Injuries
Bloom et al. (133)	Not stated	Cross-Sectional: retrospective survey	Male and female university athletes, Montreal, Quebec	Concussion		**Head Injuries (mean):** Male = 3.39 (SD = 2.66), Female = 2.58 (SD = 1.58) **Non-recognized Head Injuries:** Male = 89.4%, Female = 82.9%
Meeuwisse et al. (102)	2 years	Prospective cohort study	Male university basketball players, Canada	Concussion	**Relative Risk:** RR = 4.0 (95% CI: 1.11 – 14.37) if player has a history of HI	
Swenson (132)	2005 - 2008	Descriptive Epidemiological: prospective observation of injury surveillance system	High school athletes (football, boys' and girls' soccer, boys' and girls' basketball, girls' volleyball, wrestling, baseball, softball), USA	Concussion		**Subsequent Head Injuries:** 11.6%; 12.4% football*, 13.8% boys' soccer*, 19.1% girls' soccer*, 14.8% girls' volleyball, 2.2% boys' basketball, 13.7% girls' basketball*, 9.6% wrestling*, 31.9% baseball*, 11.8% softball* *Greater proportion than new injuries

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Chapter 3

Epidemiology of Sport and Recreation Related Head Injuries Presenting to Emergency Departments

3.1. Introduction

There are 1.4 million head injuries sustained annually in the United States that present to an ED.(1) Of these, approximately 300,000 (21%) occur from sports and recreation; however only head injuries with a loss of consciousness (LOC) are included in this estimate.(1-3) Recent estimates, however, suggest that 300,000 dramatically underestimates the occurrence of sports and recreation related head injuries, and that anywhere from 1.6 to 3.8 million sport and recreation related head injuries may occur annually, including those for which no treatment is sought.(2) Because of the high incidence of head injuries occurring in sports and recreational activities, sport and recreation related head injuries is a major public health concern.

Prospective and retrospective studies have documented the incidence of head injury for various sports; however, the majority of sport and recreation research has been performed on elite high school, college and university, and professional athletes. Although Canadian studies have also investigated head injuries from sports and recreation, few have investigated head injuries in a large population-based sample. This study sought to describe the epidemiology of head injuries occurring in sports and recreational activities in a Canadian population-based sample.

3.2. Methods

The Ambulatory Care Classification System (ACCS) is an administrative health database used in Alberta to collect patient data when presenting at EDs. All five EDs in Edmonton, the Grey Nun's Community Hospital, the Misericordia Community Hospital, the Royal Alexandra Hospital, the Sturgeon Community Hospital, and the University of Alberta Hospital, contribute information to the ACCS. The data provided were combined from five separate files (one per each ED) based on a unique identifier field supplied in the datasets.

The ACCS database is maintained by the Capital Region, Alberta Health Services (formerly the Capital Health Authority) and includes information on sex, age, date of presentation, 10 diagnosis and procedure fields, disposition, as well as a triage score. The Canadian Emergency Department Triage and Acuity Scale is a five level coding system (Table 3.1) used in Canadian EDs to indicate which individuals presenting to EDs need to be seen/treated first and who can safely wait.(4)

Table 3.1 Canadian Emergency Department Triage and Acuity Scale (CTAS)

CTAS Score	Description	(e.g.) Head Injury
I	Resuscitation	GSC < 10
II	Emergent (Emergency)	GSC ≤ 13, severe head ache, LOC, nausea, vomiting
III	Urgent	GSC = 15, nausea, vomiting
IV	Less Urgent (Semi-Urgent)	GSC = 15, minor head injury, no vomiting
V	Non-Urgent	GSC = 15, contusions, abrasions, lacerations

Adapted from: Beveridge et al. (1998). Implementation Guidelines for The Canadian Emergency Department Triage & Acuity Scale (CTAS).

The ACCS database contains ICD-9 codes (prior to April 1st, 2002) and ICD-10 codes (after April 1st, 2002) as well as a sport and recreation coding system. The sports and recreation coding system contains more than 120 codes which are used to identify SR activities engaged in prior to presenting at an ED (Appendix A). Data previously collected and documented in the ACCS between April 1st, 1997 and March 31st, 2008 were used in this study.

Inclusion Criteria

Head injury was defined as an ICD-9-CM (5) or ICD-10-CA (6) injury diagnosis of skull fracture (*800, 801, 803, 804, S02 – S021, S027 – S029*), intracranial injury (*850 – 854, S06*), crushing injury of the head (*925, S07*), and fractures involving the head and neck (*T02 – T021*). All ten diagnosis fields were searched for a head injury code. Sport and recreation categories were condensed from the original coding in the ACCS database into similar SR activities. For instance, animal related contained chuck wagon racing, horseback riding/jumping, and show jumping. Baseball contained baseball, tee-ball, slow pitch, soft ball, and cricket. Cycling contained cycling, cycling passenger, unicycle, BMX, and mountain biking. OHVs contained ATVs, snowmobile, dirt bike, motor cross, towed behind snowmobile on toboggan, pocket/rocket/mini-moto bikes, auto racing, and go carting. Playground equipment contained play ground equipment, sliding poles, fall from playground platforms > 4 feet, merry-go-round, teeter totter, monkey bars, slides, swings, and trampoline. Skating/ skateboarding contained skateboarding, mountain boarding, non-motorized scooters, roller skates/wheely/heely shoes, rollerblading, ice skating, figure skating, and speed skating. Skiing/snowboarding contained skiing, snowboarding, snow-skating, ski jumping, cross country skiing, downhill skiing, ski boards/ski blades, tobogganing sledding snow tubing, and luge/bobsled. The SR groups of basketball, football, rugby, and soccer contained only a single activity from the ACCS. Of the groupings, twelve groups contained more than 100 head injuries and remained as unique groups while all other activities formed the thirteenth group labelled "Occurring in Other Sports and Recreation" (see Appendix B for final groupings).

To identify SR injury records that may not have been coded as SR injuries, a supplementary search of all 10 diagnosis fields, using ICD-9 *supplementary classification of external causes of injury and poisoning* codes (E-codes)(5) and ICD-10 *external causes of morbidity and mortality* codes (Chapter 20),(6) for each record in the dataset (Appendix B). Children less than 5 years of age were included in the analysis as research has indicated that this age group may have the highest rates of head injury.(7,8) The inclusion of children less than 5 years also captures head injuries that occur in common recreation activities (e.g., sledding, playground equipment, etc) that would otherwise be excluded.

Exclusion criteria

Adults over 35 years of age were not included in the study as previous work has shown relatively low rates of SR head injuries in this age group.(1,9) Records were excluded from the analysis if the record: 1) was not for a resident of the Capital Health Region, as identified by postal code prefixes, 2) did not have a diagnosed head injury, 3) had any diagnosis code ranging from *V00 – V89* (ICD-9

Supplementary Classification of Factors Influencing Health Status and Contact with Health Services) or *Z00 – Z99* (ICD-10 Factors Influencing Health Status and Contact with Health Services), 4) was a transfer from another health care facility, or 5) was a repeat visit to an ED within a span of 14 days from any injury.

Analysis

Continuous variables were analyzed using two-group mean comparison t-tests, reporting two-tailed p-values for unpaired data (using unequal variance calculations when two-group variance comparison tests reported significant p-values ($p < 0.05$)). Categorical variables are reported as odds ratios with 95% CIs or the proportion of cases with corresponding p-values. Data were analyzed using Stata version 10.(10) Ethical approval for this study was granted by the University of Alberta's Health Research Ethics Board.

3.3. Results

According to Statistics Canada, the 1996 population for the Census Metropolitan Area (CMA) for Edmonton and surrounding area was 862,597, the median age of the population was 34.0, and 78.0% of the population was 15 years of age and older.(11) In 2006, the population of the CMA for Edmonton and surrounding area was 1,034,945, the median age of the population was 36.4 years, and 81.9% of the population was 15 years of age and older.(12)

From April 1st, 1997 until March 31st, 2008, there were 3,230,890 ED visits to the five EDs in Edmonton, Alberta, of which 964,172 (29.84%) were presentations to an ED that received an injury diagnosis (Humeniuk B 2010, personal communication, May 4th). Of these injury cases, 131,210 observations (13.61%) were documented within the ACCS as a sport or recreation injury. The supplementary search of the injury diagnosis fields indicated an additional 750 records that were considered a SR event. The final analysis contained 12,831 head injuries (1.3% of injury visits) with ED records for 12,234 unique identifiers. Events identified as a sport or recreational event accounted for 38.6% (n = 4,950) of the head injuries observed.

The age of individuals in the final analysis ranged from less than 1 year of age to 35 years of age (median = 17, IQR = 12, 24). The mean age at the time of presentation for those with a SR related head injury was 16.0 years of age (SD = 6.7) compared to 18.3 years of age (SD = 10.0) for non-SR activities ($p < 0.0001$). Individuals with head injuries from SR were significantly younger than those with head injuries not occurring in SR regardless of the number of head injuries observed (first head injury $p < 0.0001$, second head injury $p < 0.0001$, third head injury $p < 0.0001$).

Males accounted for 8,855 (69.0%) of the head injuries and were 1.25 times more likely (95% CI: 1.16, 1.35) than females to present to an ED with a head injury from SR. Children (less than 18 years of age) accounted for 51.7% (6,638) of all head injuries and 69.8% (3,453) of the head injuries documented from SR activities. Children were 3.4 times more likely (95% CI: 3.15, 3.67) to present to an ED with a head injury from SR than individuals 18 years of age and older. Males less than 18 years of age were 4.1 times more likely (95% CI: 3.75, 4.50) to present to an ED with a head injury from SR than males 18 years of age and older. Females less than 18 years of age were 2.3 times more likely (95% CI: 1.99, 2.61) to present to an ED with a head injury from SR than females 18 years of age and older.

The rates of head injury across age groups are presented in Table 3.2 and 3.3. [1] The highest rates of head injury from SR were observed for those 14 – 17

Table 3.2 Rates of Sport and Recreation Related Head Injuries

Age	Rate per 1,000 ED visits	Rate per 1,000 Injury Diagnosis	Rate per 1,000 SR Injury Diagnosis
0 - 6	0.09	0.30	2.21
7 - 13	0.47	1.56	11.49
14 - 17	0.51	1.72	12.62
18 - 22	0.22	0.74	5.41
23 - 26	0.11	0.36	2.62
27 - 30	0.07	0.23	1.66
31 - 35	0.07	0.23	1.71
0 - 35	1.53	5.13	37.73

Table 3.3 Rates of Non-Sport and Recreation Related Head Injuries

Age	Rate per 1,000 ED visits	Rate per 1,000 Injury Diagnosis	Rate per 1,000 Non-SR Injury Diagnosis
0 - 6	0.44	1.49	1.72
7 - 13	0.26	0.86	0.99
14 - 17	0.29	0.96	1.11
18 - 22	0.56	1.87	2.16
23 - 26	0.34	1.13	1.3
27 - 30	0.27	0.89	1.03
31 - 35	0.29	0.99	1.14
0 - 35	2.44	8.17	9.46

[1] Rates for SR injury diagnosis are based on the number of cases identified as an SR injury in the

years old, while the highest rates of head injury for non-SR activities were observed for those 18 – 22 years old. For injuries that were identified as SR related, the overall rate was 37.7 head injuries/1,000 SR related injury diagnoses—four times more than non-SR related injuries (RR = 3.99).

Table 3.4 shows the frequency and percentage of head injuries by age group for SR and non-SR activities. For non-SR related injuries, the greatest frequency of head injuries were seen for those 0 – 6 years of age (n = 1,436; 18.2%), 18 – 22 (1,799; 22.8%), and 23 – 26 (1,086; 13.8%). Head injuries from SR activities were most commonly seen for those 7 – 13 years of age (1,507; 30.4%), 14 – 17 (1,656; 33.5%), and 18 – 22 (710; 14.3%).

Table 3.4 Head Injuries by Age Group

	SR Activities		**Non-SR Activities**	
Age Group	**Head Injuries**	**HI%**	**Head Injuries**	**HI%**
0 - 6	290	5.90%	1,436	18.20%
7 - 13	1,507	30.40%	828	10.50%
14 - 17	1,656	33.50%	921	11.70%
18 - 22	710	14.30%	1,799	22.80%
23 - 26	344	6.90%	1,086	13.80%
27 - 30	218	4.40%	860	10.90%
30 - 35	225	4.50%	951	12.10%

Frequency of Emergency Department Visits

The frequency of ED visits for SR and non-SR injuries is shown in Table 3.5. The frequency of ED visits ranged from 1 – 3 for SR related head injuries and 1 – 4 for non-SR head injuries. Ninety-six percent (n = 4,736) of SR head injuries and 97% of non-SR head injuries were an index presentation (first observed visit to an ED for the corresponding unique identifier). The median number of ED visits for those presenting from both SR and non-SR activities was 1 (IQR = 1, 1). A non-parametric test for equality of medians (equally splitting ties above and below the median) indicated no statistical difference between the median number of ED visits for the SR and non-SR groups ($\chi^2 = 0.7359$, $p = 0.391$).

Table 3.5 Frequency of Head Injuries

	SR Group		Non-SR Group	
ED Visits	**Injuries**	**Percent**	**Injuries**	**Percent**
1	4,736	95.68%	7,664	97.25%
2	201	4.06%	201	2.55%
3	13	0.26%	14	0.18%
4	0	0%	2	0.03%

The number of days between head injury presentations to an ED ranged from 19 to 3,187 for SR injuries and from 17 to 3,900 for non-SR injuries. The median duration between subsequent visits to the ED for SR head injuries was 607.5 days (IQR = 280, 1,173) and 723 days (IQR = 218, 1,462) for head injuries from non-SR activities (test for equality of medians, p = 0.31).

Sport and Recreation Activity

The frequency and proportion of injuries that were attributed to the most common SR activities are presented in Table 3.6. Sports and recreational activities with the highest proportion of head injuries were hockey (20.7%), cycling (12.0%), skiing/snowboarding (10.6%), soccer (8.8%), and football (6.4%).[2] For those who sustained more than one SR head injury[3], subsequent head injuries were observed to primarily result from hockey (n = 86, 40.2%), football (n = 23,

[2] *Occurring in Other Sports and Recreation* accounted for 16.5% of head injuries.
[3] *Occurring in Other Sports and Recreation* accounted for 10.7% of subsequent head injuries.

10.7%), and soccer (n = 23, 10.4%). With the exception of animal related events, males sustained more head injuries in all of the SR groups. For individuals who sustained a head injury due to SR, Table 3.7 displays the odds of males sustaining a head injury for each of the SR groups, compared to females. Males were

Table 3.6 Frequency of Sport and Recreational Head Injuries

Sport & Recreation Activity	**Males Head Injuries (%)**	**Females Head Injuries (%)**	**Total Head Injuries (%)**
Hockey	926 (90.3%)	100 (9.7%)	1026 (20.7%)
Cycling	467 (78.5%)	128 (21.5%)	595 (12.0%)
Skiing /Snowboarding	345 (65.6%)	181 (34.4%)	526 (10.6%)
Soccer	244 (55.7%)	194 (44.3%)	438 (8.8%)
Football	303 (95.9%)	13 (4.1%)	316 (6.4%)
Skateboarding/Skating	170 (68.3%)	79 (31.7%)	249 (5.0%)
Playground Equipment	141 (57.1%)	106 (42.9%)	247 (5.0%)
OHV/ATV	164 (77.7%)	47 (22.3%)	211 (4.3%)
Rugby	105 (58.3%)	75 (41.7%)	180 (3.6%)
Basketball	65 (55.1%)	53 (44.9%)	118 (2.4%)
Animal Related	25 (21.9%)	89 (78.1%)	114 (2.3%)
Baseball	60 (56.6%)	46 (43.4%)	106 (2.1%)
Occurring in Other SR Activities	545 (66.1%)	279 (33.9%)	824 (16.6%)
All SR Activities	3560 (71.9%)	1390 (28.1%)	4,950 (100%)

Table 3.7 Odds Ratio for Males Sustaining a SR Head Injury by Activity

Sport & Recreation Activity	**OR (male)**	**95% CI**		**P-Value**
Football	9.85	5.64	17.23	**< 0.001**
Hockey	4.54	3.65	5.63	**< 0.001**
Cycling	1.49	1.21	1.83	**< 0.001**
OHV/ATV	1.38	0.99	1.92	0.056
Skateboarding/Skating	0.83	0.63	1.10	0.19
Occurring in Other SR Activities	0.72	0.61	0.85	**< 0.001**
Skiing /Snowboarding	0.72	0.59	0.87	**0.001**
Rugby	0.53	0.39	0.72	**< 0.001**
Playground Equipment	0.50	0.39	0.65	**< 0.001**
Baseball	0.50	0.34	0.74	**< 0.001**
Basketball	0.47	0.33	0.68	**< 0.001**
Soccer	0.45	0.37	0.55	**< 0.001**
Animal Related	0.10	0.07	0.16	**< 0.001**

significantly more likely to sustain a head injury if participating in football, hockey, or cycling. Males were significantly less likely to sustain a head injury from skiing/snowboarding, rugby, playground equipment, baseball, basketball, soccer, animal related, and other SR activities.

Triage

The frequency and proportion of triage coding is shown in Table 3.8. Significantly fewer SR head injuries resulted in triage codes for *Resuscitation* (p < 0.0001), *Emergency* (p < 0.0001), and *Non-Urgent* (p = 0.005). A significantly higher proportion of SR head injuries were coded as *Urgent* (p < 0.0001) and *Unavailable* (p = 0.032), while no significant differences in the proportion of head

Table 3.8 Frequency and Percentage of Triage Codes

Triage (CTAS)	**SR**	**Non-SR**	**Total**	**% of total from SR**	**SR% vs. non-SR%**	**P - Value**
Resuscitation (1)	47	326	373	12.60%	0.95% vs. 4.14%	**P < 0.0001**
Emergency (2)	476	1,075	1,551	30.70%	9.62% vs. 13.64%	**P < 0.0001**
Urgent (3)	2,437	3,291	5,728	42.50%	49.23% vs. 41.76%	**P < 0.0001**
Semi-Urgent (4)	1,180	1,928	3,108	38.00%	23.84% vs. 24.46%	P = 0.42
Non-Urgent (5)	90	220	310	29.00%	1.82% vs. 2.79%	**P = 0.005**
Unavailable	720	1,041	1,761	40.90%	14.55% vs. 13.21%	**P = 0.032**

Table 3.9 Triage Codes for SR Head Injuries

Triage (CTAS)	**Male**	**Female**	**Total**	**% Male**	**Odds Ratio**	**P - Value**
Resuscitation (1)	33	14	47	70.20%	0.92 (95% CI: 0.48, 1.87)	P = 0.79
Emergency (2)	357	119	476	75.00%	1.19 (95% CI: 0.95, 1.49)	P = 0.12
Urgent (3)	1,777	660	2437	72.90%	1.10 (95% CI: 0.97, 1.25)	P = 0.12
Semi-Urgent (4)	828	352	1180	70.20%	0.89 (95% CI: 0.77, 1.05)	P = 0.13
Non-Urgent (5)	64	26	90	71.10%	0.96 (95% CI: 0.60, 1.59)	P = 0.86
Unavailable	501	219	720	69.60%	0.88 (95% CI: 0.73, 1.05)	P = 0.13

injuries coded *Semi-Urgent* between SR vs. non-SR cases were observed (p = 0.42). No statistically significant differences were observed between the proportion of males and females presenting with a SR related head injury for any triage code (p > 0.10) (Table 3.9).

Disposition

Table 3.10 displays the disposition for individuals who presented to an ED for SR and non-SR head injuries. Individuals who sustained head injuries from SR were discharged 3.44 times more often (95% CI: 3.02, 3.93), compared to head injuries from non-SR activities. Significantly fewer head injuries from SR resulted in fatalities (p = 0.0001) and fewer SR head injuries left against medical advice/left before being seen (p = 0.0008). No statistically significant differences

Table 3.10 Disposition After Presenting at Emergency Department

Disposition	**SR**	**Non-SR**	**% SR vs. % Non-SR**	**P - Value**
Admitted	276	1,310	5.58% vs. 16.62%	**P < 0.0001**
Discharged	4,657	6,478	94.08% vs. 82.20%	**P < 0.0001**
Left Early/Against Advice	*	63	*	**P = 0.0008**
Fatality	*	30	*	**P = 0.0001**

*Suppressed due to small cell size

Table 3.11 Disposition for SR Head Injuries

Disposition **(SR HI only)**	**Male**	**Female**	**Odds Ratio**	**P - Value**
Admitted	195	81	0.94 (95% CI: 0.71, 1.24)	P = 0.63
Discharged	3,353	1,304	1.07 (95% CI: 0.81, 1.39)	P = 0.62
Left Early/Against Advice	*	*	*	P = 0.78
Fatality	*	*	*	P = 0.53

*Suppressed due to small cell size

were observed between the proportion of disposition codes for males and females who presented with a head injury from SR ($p > 0.50$) (Table 3.11).

Diagnoses

Records with a primary diagnosis of head injury accounted for 11,552 of the 12,831 head injuries (90%). The most common type of injury for those with a primary diagnosis of head injury was intracranial injury (Table 3.12). Sport and recreation related injuries had a significantly higher proportion of head injuries as the primary diagnosis compared to non-SR injuries (93% vs. 88%; $p < 0.001$). SR injuries also had a significantly higher proportion of injuries with a primary diagnosis of concussion than non-SR injuries (83% vs. 62%; $p < 0.001$).

Table 3.12 Primary Head Injury Diagnosis

Injury Type	**ICD-9**		**ICD-10**	
	Non-SR	**SR**	**Non-SR**	**SR**
Fracture	353	63	389	80
Intracranial Injury	2,912	1,983	3,298	2,471
Crushing Injury	*	*	*	*

*Suppressed due to small cell size

The frequency and percentage of concussions sustained for SR and non-SR injury presentations, and the corresponding LOC for records which contained a primary diagnosis of concussion are presented in Table 3.13. There is, however, no research on the reliability of this coding. Significantly more SR head injuries with a primary diagnosis of concussion were classified as a concussion with a brief loss of consciousness (26% vs. 22%; $p < 0.0001$). Compared to non-SR head injuries, fewer SR head injuries with a primary diagnosis of concussion sustained a moderate LOC (p = 0.0025), or a concussion with an unspecified LOC (12% vs. 18%; p < 0.0001). There was no significant difference in the proportion of head injuries with a primary diagnosis of concussion that were indicated as a concussion with no loss of consciousness (60% vs. 62%; p = 0.091) or concussions with a prolonged LOC (p = 0.41).

Table 3.13 Primary Diagnosis of Concussion by Concussion Type

Diagnosis	**Sport and Recreation**		**Non-Sport and Recreation**		**P-Value**
	(n)	**(%)**	**(n)**	**(%)**	
Concussion (No LOC)	2,515	62%	2,905	60%	0.091
Concussion (Brief LOC)	1069	26%	1055	22%	**< 0.0001**
Concussion (Moderate LOC)	*	*	*	*	**0.0025**
Concussion (Prolonged LOC)	*	*	*	*	0.41
Concussion (Unspecified LOC)	497	12%	875	18%	**< 0.0001**

*Suppressed due to small cell size

Procedures

Of the 12,831 head injuries, 43.5% (n = 5,582) did not have any documented procedures. Nearly 55% of SR injuries and 61.7% of non-SR events with a primary diagnosis of head injury did not have any associated procedures. For sport and recreation related injuries where the primary diagnosis was a head injury, there were 184 unique procedure codes identified in the primary procedure field. For records that contained a primary diagnosis of head injury, individuals from SR events were significantly younger than those with non-SR events (15.12 yrs (SD = 5.9) vs. 15.85 yrs (SD = 10.1); p = 0.0016). For SR records with a primary diagnosis of head injury, males were 15% less likely (OR = 0.85; 95% CI: 0.79, 0.92) than females to have a documented procedure. Compared to non-

SR head injuries, records with a primary diagnosis of head injury from SR were 1.94 times more likely (95% CI: 1.80, 2.09) to not have an accompanying code in the primary procedure field.

Of the records with a primary diagnosis of head injury from SR that had a documented procedure code, 70.7% received a CT scan to the head, face, neck, or spine, 3.8% received an X-Ray to the head, neck, face, or spine, and less than 1% received an MRI to the head, neck, face, or spine. Other procedures, including CT scans and X-Rays to other body regions, accounted for 12.7% of the primary procedure field.

Table 3.14 displays the odds of primary diagnosed head injuries from SR having a documented primary procedure. Individuals with a primary diagnosis of a head injury from SR were 33% less likely receive a CT scan to the head, neck, or face (OR = 0.67; 95% CI: 0.62, 0.72). There were no statistically significant differences between SR and non-SR head injuries receiving X-rays (OR = 0.82; 95% CI: 0.63, 1.07) or MRIs (OR = 0.30; 95% CI: 0.01, 2.7) to the head, neck, or face. Individuals with SR head injuries were significantly less likely to have any

Table 3.14 Odds of SR Head Injuries with a Documented Primary Procedure

Procedure	Odds Ratio	95% CI	P-Value
Head CT	0.67	0.62, 0.72	**< 0.0001**
Head X-Ray	0.82	0.63, 1.07	0.13
Head MRI	0.30	0.01, 2.7	0.25
Other CT	0.36	0.19, 0.63	**0.0001**
Other X-Ray	0.86	0.70, 1.06	0.145
Other Procedure	0.35	0.28, 0.42	**<0.0001**
No Procedure	1.94	1.80, 2.09	**< 0.0001**

other procedure documented (OR = 0.35; 95% CI: 0.28, 0.42) and almost twice as likely to have no procedures documented (OR = 1.94; 95% CI: 1.80, 2.09).

3.4. Discussion

Head injuries from SR activities accounted for 39% of head injuries presenting to EDs in this population based study. The percentage of head injuries that presented to an ED that were attributed to SR was greater than the 24% previously reported in Edmonton (9), but similar to the 32% reported in Australia(13) and the 42% of minor head injuries occurring from sports and physical recreation reported in Kingston, Ontario.(14) Although 40% of head injuries in the present study were attributed to SR activities, when the groups of *sports and recreation* and *leisure and recreation* from other studies (13,14) are combined, the proportion of head injuries attributed to SR increases to 49% (13) and 63%.(14) However, inclusion criteria such as head injury definitions, age restrictions, and the length of these studies are problematic for accurate comparisons. A substantial percentage of SR head injuries were sustained by children. The 70% of SR head injuries sustained by individuals less than 18 years of age is slightly greater that the 66% previously reported in Edmonton (9) for people less than 20 years of age, and the 65% reported in the United States for children 5 – 18 years of age.(3)

Five of the thirteen SR activity groupings (hockey, cycling, skiing/snowboarding, soccer, and football) accounted for 59% of head injuries from SR, which is similar to previous research in Edmonton.(9) The greatest number of SR head injuries presenting to EDs are commonly cited as hockey, cycling, football, playground activities, rugby, and soccer.(3,9,15) Cycling has also been shown previously to account for the high percentage of SR injury visits to EDs.(3,9,15) The observation that 12% of SR head injuries were due to cycling is consistent with that observed by Kelly et al.(9) who observed 12% of all head injuries were due to cycling while only 8% of cycling head injuries were due to SR. Consequently, it is likely that by including all cycling events as SR activities, a number of cycling-related head injuries that were actually transport related were incorrectly identified as SR injuries. However, the majority of cycling has been observed to be primarily fitness or recreation related.(16) Surprisingly, skiing/snowboarding/sledding accounted for the third most head injuries (10.6%), more than both football and soccer. Soccer accounted for the fourth most head injuries (8.8%), a percentage similar to previous findings.(9,13)

With the exception of animal related activities, males sustained a greater proportion of head injuries in all of the 13 SR events. Males were significantly more likely to sustain head injuries in the activities of football, hockey, and cycling, yet significantly less likely to sustain a head injury in skiing/snowboarding/sledding, rugby, playground equipment, baseball, basketball, soccer, animal related activities, and other sport and recreational activities (Table 3.6).

These results appear to support the findings that females are more likely to sustain head injuries in comparable activities,(17) that male and females both participate in. Although females also participate in hockey, girls' and women's hockey does not allow body-checking at any level, which likely accounts for the reduced risk of head injury in hockey. One of the limitations to using this administrative data is that it was not possible to determine at which level of competition head injuries occurred most frequently (i.e., competitive vs. recreational leagues or divisions). Although it may be possible to use age as a proxy to compare head injuries between various levels of activity (i.e., high school, college, etc) this presents numerous complexities and was therefore not investigated in this study.

The inclusion of children less than 5 years of age pertains more to recreational activities than participation in sports. For instance, playground activities and tobogganing are examples of where children under 5 could sustain head injuries in SR. Also, the purpose of this study was to investigate SR head injuries using population-based data, thus children under 5 were included in contrast to the majority of SR research that focuses on high-school or college aged samples. Adults over 35 years of age were not included in the study as previous work has shown low rates of SR head injuries in this age group.(1,9) In this study, children less than 18 years of age accounted for 70% of head injuries from SR and children 9 – 17 years of age accounted for a greater frequency and proportion of head injuries from SR than the non-SR group. The average age of individuals presenting with a head injury was nearly 2 years younger in the SR than the non-SR group. The pre-teen and adolescent populations participating in SR should be a priority target group when implementing programs aimed at reducing head injuries.

The average age for SR head injuries increased only slightly (16.0, 16.3, 17.2) as the number of SR head injuries increased, while the age for those with non-SR head injures (18.2, 22.8, 26.9) had larger increases as the head injury count rose. The average number of weeks between head injuries presenting to an ED for the SR group was nearly 32 weeks (223 days) fewer than the non-SR group. The relatively small increase in average age between the observed head injuries in the SR group may be due to increased participation in SR at younger ages, increased risky behaviour, inappropriate care for head injuries, such as returning to competition prior to recovery or a potential continued lack of safety equipment such as helmets, or potentially related to an increased frequency of presentations by children at an ED; however, this remains unclear.

The average number of subsequent ED visits did not significantly differ (1.06 vs. 1.08; $p = 0.41$) for individuals presenting with SR and non-SR related head injuries. Using the documented triage codes, ED disposition, and procedure codes as a proxy for severity of injury, head injuries from non-SR activities were estimated to be more severe than head injuries from SR activities. A greater proportion of non-SR head injuries were coded as Resuscitation and Emergency, were less likely to be discharged from the ED, and a greater proportion received CT scans or other procedures, which may indicate a greater severity of head injury or multiple traumas. The high percentage of SR head injuries that were discharged (94%) is similar to other studies.(14,18)

Although significant differences were observed between the proportions of head injuries with a primary diagnosis of concussion, the overall pattern of concussion LOC between the SR and non-SR groups was similar. Although nearly half of all SR head injuries did not have an accompanying primary procedure code, the most common primary procedure for those with a SR head injury was a CT scan to the head, neck/spine, or face.

It is however, difficult to precisely compare the results of the current study with previous population based research as varying definitions of head injury, inclusion/exclusion criteria, and variations in methods exist. For instance, studies commonly exclude children less than 5 years of age,(13,15,18); however, since recreation activities were also investigated in this study, head injuries for young children occurring in activities such as cycling, playground activities, ice skating, and sledding have been captured when they would have otherwise been missed.

Also, although the GCS has been used as an inclusion criteria in other studies,(13,14) it was not available in the ACCS database to investigate head injury by a range of severity. While ICD-9 and ICD-10 codes have been used to identify head injuries from sports and recreation that were a primary or secondary diagnosis,(15,18,19) the present study included a head injury from any of the ten diagnosis fields. The sport and recreation codes that are included in the ACCS are likely to have increased the level of detail for identifying which SR activity was engaged in (specific activity vs. general recreation or leisure), while other studies are generally limited to a few ICD-9 or ICD-10 codes that indicate a SR event.(15,18)

Limitations

It is important to indicate a number of limitations to this study. First, any head injury that was sustained and did not seek medical attention or sought medical attention from walk-in clinics, other physician offices, physical therapists, or athletic therapists was not captured by the ACCS database. Therefore, due to the use of a convenience sample, it is possible that selection bias may have severely underestimated the number of SR head injuries observed as it has been estimated that only 35% of SR head injuries seek medical attention at an ED.(20)

Second, general limitations exist from using administrative data. Although all 10 diagnosis fields were searched for external cause of injury codes to identify undocumented SR head injuries, due to the groupings of some ICD-9 and ICD-10 codes it is not possible to extract all SR activities as many of the codes pertain to broad definitions. Possible coding errors in the ACCS also contribute to the limitations of using administrative data; however, previous research in local EDs has reported that false positives (i.e., observations that had no mention of head injury in their ED chart, yet were coded as head injury in the ACCS) is quite small (3%).(9) Therefore it was assumed that errors within the ACCS did not significantly impact the findings.

Also, combining a wide range of SR activities into one general category (*Occurring in Other Sport and Recreation*) due to a small number of specific events may also have resulted in unintended misclassification; however, it is believed that any affect this would have had is limited. Finally, it is not possible to calculate rates of SR head injuries per time at risk of SR injury or the usage of protective equipment, such as helmets, as this data is not collected in the ACCS.

Strengths

By using the ACCS administrative database, this study was able to identify all head injuries that presented to any ED in the City of Edmonton, Alberta. Also, various sports and recreational activities that are participated in frequently, yet not commonly researched, such as sledding/tobogganing, skateboarding, rollerblading, and ice skating, were identified through the use of the ASSC administrative database. Furthermore, this study was able to capture SR head injury events from popular team sports such as hockey, football, rugby, soccer, and basketball, at earlier ages than the majority of the SR head injury literature.

3.5. Conclusion

In this study, head injuries from sport and recreation accounted for 39% of head injuries treated in EDs in the City of Edmonton. As the highest rates of SR head injuries were seen for children in the 14 – 17 and 7 – 13 year old age groups, concern over the cumulative effects of head injuries in these younger populations should be a major focus of injury prevention initiatives.

From a public health perspective, the promotion, legislation, and enforcement of protective head gear and the use of such equipment, as well as the consequences of not wearing helmets needs to increase—specifically within recreational activities such as skiing, snowboarding, sledding, skateboarding, and rollerblading. Head injuries commonly occur in hockey and football, even though helmets and protective equipment is required to play in organized leagues. This may indicate that various leagues and organizations need to increase the education and training of coaches, officials, volunteers, and players in regards to head injuries and their corresponding implications. Alternatively, there have been calls for delayed body checking or the elimination of body checking in youth hockey(21-23); further policy work is encouraged to protect these vulnerable players.

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Chapter 4

Subsequent Head Injuries Occurring from Sports and Recreational Activities

4.1. Introduction

Head injuries are known to affect a number of cognitive functions, including cognitive processing speed, verbal and visual memory, planning skills, and reaction time.(1-5) As a result of elite athletes sustaining multiple head injuries, the attention to the cumulative effects of head injuries has increased. Although numerous studies have investigated the cumulative effects of head injury,(2,3,6-16) different methodologies and samples have resulted in various results. These cumulative effects are also associated with prolonged recovery from subsequent head injuries, a diagnosis of mild cognitive impairment, depression, and Alzheimer's disease.(6-8)

Among those who participate in sports at an elite level, the odds of sustaining a subsequent head injury ranges from 1.4 – 11.1 times, if a previous history of head injury exists.(8,17-25) Other studies have observed that the average number of head injuries sustained in a one year period to be 3.4 for males and 2.6 for females,(26) while the percentage of subsequent head injuries occurring within a single athletic season has been observed to range from 1% to 24%.(8,20,27)

Although the magnitude of the effects of multiple head injuries is unclear, research has focused primarily on the individuals who participate in elite level contact sports. This, however, fails to account for the majority of participants—the general population—who participate in sports and recreational activities.

There were three objectives to this study. The primary objective was to determine the odds of sustaining a subsequent head injury from sports and recreational activities, if a history of past sport and recreation related head injuries existed using a large Canadian population based sample. The secondary objectives were 1) to determine whether the time between head injuries decreased significantly as the number of head injuries increased, and 2) to identify which sport and recreational activities were significant predictors of head injuries presenting to EDs.

4.2. Methods

This retrospective, longitudinal cross-sectional study was conducted in Edmonton, Alberta, Canada. There are five EDs located in the City of Edmonton. All five EDs contribute data to the Ambulatory Care Classification System (ACCS). The ACCS is an administrative health database, maintained by the Capital Region, Alberta Health Services. Data from the ACCS from April 1st, 1997 to March 31st, 2008 inclusive were used for this study. The ACCS contains patient information including sex, age, date of presentation, and ten diagnosis and procedure fields. A sport and recreation code is also maintained in the ACCS, which includes more than 100 separate sport and recreational activities (Appendix A).

Sport and recreation categories were condensed from the original coding in the ACCS database into similar SR activities. For instance, animal related contained chuck wagon racing, horseback riding/jumping, and show jumping. Baseball contained baseball, tee-ball, slow pitch, soft ball, and cricket. Cycling contained cycling, cycling passenger, unicycle, BMX, and mountain biking. OHVs contained ATVs, snowmobile, dirt bike, motor cross, towed behind snowmobile on toboggan, pocket/rocket/mini-moto bikes, auto racing, and go carting. Playground equipment contained play ground equipment, sliding poles, fall from playground platforms > 4 feet, merry-go-round, teeter totter, monkey bars, slides, swings, and trampoline. Skating/skateboarding contained skateboarding, mountain boarding, non-motorized scooters, roller skates/wheely/heely shoes, rollerblading, ice skating, figure skating, and speed skating. Skiing/snowboarding contained skiing, snowboarding, snow-skating, ski jumping, cross country skiing, downhill skiing, ski boards/ski blades, tobogganing sledding snow tubing, and luge/bobsled. The SR groups of basketball, football, rugby, and soccer contained only a single activity from the ACCS.

A supplementary search of all diagnosis fields for each ED visit, using ICD-9 (28) and ICD-10 (29) external cause codes was also conducted to identify injuries from sports and recreational events that were not originally coded (Appendix B). Twelve groups contained more than 100 head injuries and remained as unique groups while all other activities formed the thirteenth group labelled “Occurring in Other Sports and Recreation” (see Appendix B).

Inclusion Criteria

Records were included in the analysis if any of the 10 diagnosis fields contained an ICD-9-CM (28) code of *800 – 804, 810 – 829, 830 – 838*, *839.8 – 846*, *848.2 – 848.9, 850 – 854, 860 – 869, 925 – 929*, or an ICD-10-CA (29) code of *S02 – S02.4, S02.7 – S03.1, S06, S07, S22.2 – S23, S26 – S28.0, S32.3 – S32.501*, *S36 – S38.1, S42, S43, S46, S47, S49, S52, S53, S56 – S59, S62, S63, S66, S67, S69, S69, S72, S73, S76, S77, S79, S82, S83, S86, S87, S89, S92, S93, S96, S97, S99, T02 – T04, T10, T11.2, T12*, or *T13.2*.

A head injury was defined as an ICD-9-CM or ICD-10-CA injury diagnosis of skull fracture (*800, 801, 803, 804, S02 – S021, S027 – S029*), intracranial injury (*850 – 854, S06*), crushing injuries to the head (*925, S07*), and fractures involving the head and neck (*T02 – T0201*). Children less than 5 years of age were included in the analysis as research has indicated that this age group may have the highest rates of SR head injury.(30) The inclusion of children less than 5 years also captures head injuries that occur in common recreation injuries (e.g., sledding, playground equipment, etc) that may otherwise be excluded.

Exclusion Criteria

Adults over 35 years of age were not included in the study as previous work has shown relatively low rates of SR head injuries in this age group.(31,32) Records were excluded from the analysis if the record 1) was not for a resident of the Capital Region, as identified by postal code prefixes, 2) was not identified as a sport or recreation related injury, 3) had a diagnosis code of *V00 – V89* (ICD-9

Supplementary Classification of Factors Influencing Health Status and Contact with Health Services) or *Z00 – Z99* (ICD-10 Factors Influencing Health Status and Contact with Health Services), 4) indicated a transfer to or between health care facilities, 5) was a repeat visit to an ED within a 2 week period (14 days) from any injury presentation, or 6) was the only observation for the unique identifier associated with ED record.

Analysis

Kaplan-Meier time-to-event curves were created and compared with the log-rank test to illustrate the differences in survivor functions. A Cox proportional hazard model was used to determine the hazard ratio (HR) for sustaining a head injury if a history of head injuries had been previously observed, adjusting for sex and age group. A sensitivity analyses were conducted to assess whether eliminating observations that occurred within 60 days of a previous visit for the same individuals affected the results. The proportional hazard assumption was assessed by a global test of the proportional hazard model using the Schoenfeld residuals**.**

A second analysis, using logistic regression, was performed to provide estimates for the odds of sustaining a head injury from each SR activity group. Robust standard errors are reported for both the Cox and Logistic regression models to account for the within-subject correlation over multiple observations.(33) Results were considered significant if two-tailed p-values were less than 0.05. Data were analyzed using Stata version 10.(34) Ethical approval for this study was granted by the health panel of the University of Alberta's Health Research Ethics Board.

4.3. Results

In 1996, the population for the Census Metropolitan Area (CMA) for Edmonton was 862,597, the median age of the population was 34.0, and 78.0% of the population was 15 years of age and older.(35) By 2006, the population of the CMA for Edmonton had grown to 1,034,945 people, the median age of the population was 36.4, and 81.9% of the population was 15 years of age and older.(36)

There were 3,230,890 ED visits from April 1st, 1997 to March 31st, 2008 in Edmonton. Of these 3.2 million ED visits, 30% (n = 964,172) received an injury diagnosis, while injuries due to sport or recreation accounted for 13.6% (n = 131,210) of ED presentations (Humeniuk B 2010, personal communication, May 4th). Based on the inclusion criteria, there were 222,464 ED records in the ACCS. After applying the exclusion criteria, there were 63,219 (28.4%) observations remaining (Table 4.1). The data were then set up according to the conditional risk survival model for time since previous event.(37-39) The main analysis contained 9,246 ED records for 8,958 unique identifiers. The secondary analysis contained 63,219 ED records for 50,461 unique identifiers.

Head injuries accounted for 10.4% (n = 959) of the SR injuries remaining in the analysis. Males accounted for 76.9% and females accounted for 23.2% of the SR head injuries. There were 746 visits for a first head injury after an index

Table 4.1 Observations Excluded and Remaining

Observations	Number of observations	% of Total
Total	222,464	100
Removed	159,245	72.6
Not resident of the Capital Region	38,793	17.4
Not a SR event	118,317	53.2
Follow-up/after care	242	0.1
Transfers	834	0.4
Subsequent ED visit within 14 days	1,059	0.5
Conditional risk data setup*	53,973	24.3
Remaining	63,219	28.4
Main analysis	9,246	4.2
Secondary analysis	63,219	28.4

*Step preformed for main analysis only

presentation for SR injury in the ED (559 male, 187 female), 200 for a second (167 male, 33 female), and 13 for a third (11 male, 2 female). The age of subjects ranged from 1 – 35 years of age. The duration between head injuries is indicated in Table 4.2.

Table 4.2 Days Between Head Injuries

Head Injury	Subjects (n)	Median	IQR	Min	Max
1	746	758	370, 1,400	18	3803
2	200	613	287, 1,174	19	3187
3	13	303	150, 794	20	1788

The median number of days until head injury decreased as the number of head injuries increased. After an index visit, the median duration until a first head injury was 758 days, 613 days between a first and second head injury, and 303 days between a second and third observed head injury. An analysis of variance, adjusting for multiple comparisons, indicated that the average number of days until head injury was significantly different between the three groups ($F = 11.39$, $p < 0.0001$).

Kaplan-Meier time-to-event curves are presented in Figures 4.1 though 4.3. Time-to-event functions were compared by using the log-rank test. Overall, time-to-event functions were significantly different across the groups of observed head injuries ($\chi^2 = 208.93$, $p < 0.0001$; 0 previous HI vs. 1 previous HI ($\chi^2 = 168.09$, $p < 0.0001$); 0 previous HI vs. 2 previous HI ($\chi^2 = 52.57$, $p < 0.0001$); 1 previous HI vs. 2 previous HI ($\chi^2 = 7.99$, $p < 0.0047$)).

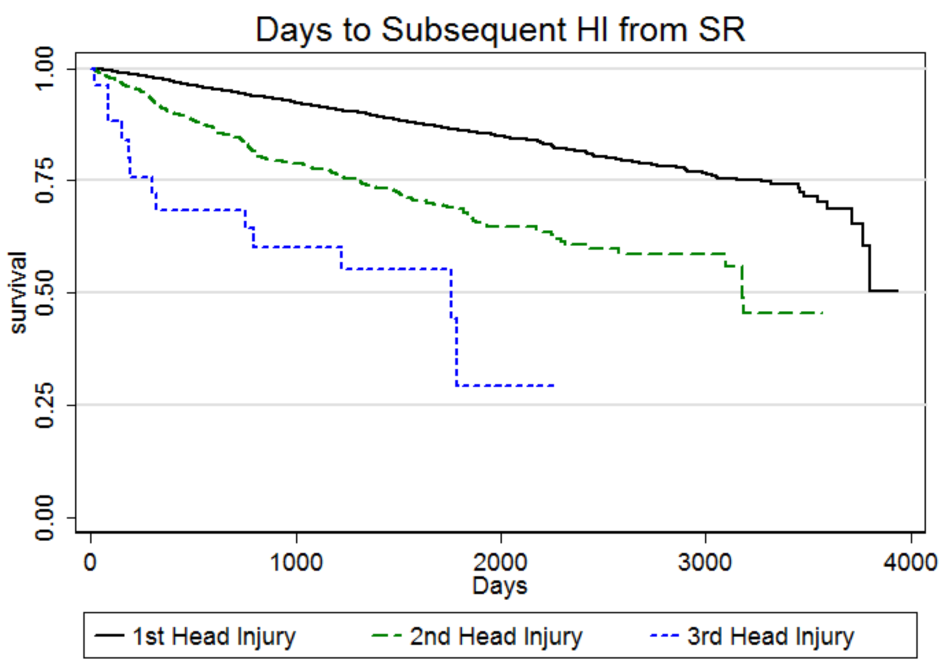

Figure 4.1 Kaplan-Meier Time-to-event Fuctions: Estimated Days to SR Head Injury Treated in an Emergency Department

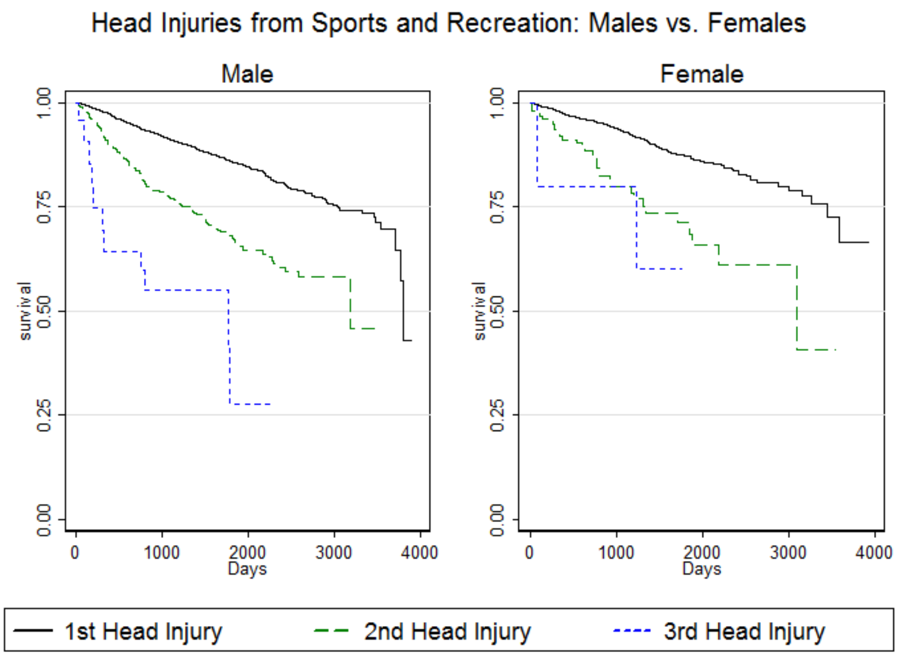

Figure 4.2 KM Time-to-event Functions by of SR Head Injury Treated in an Emergency Department: Males vs. Females

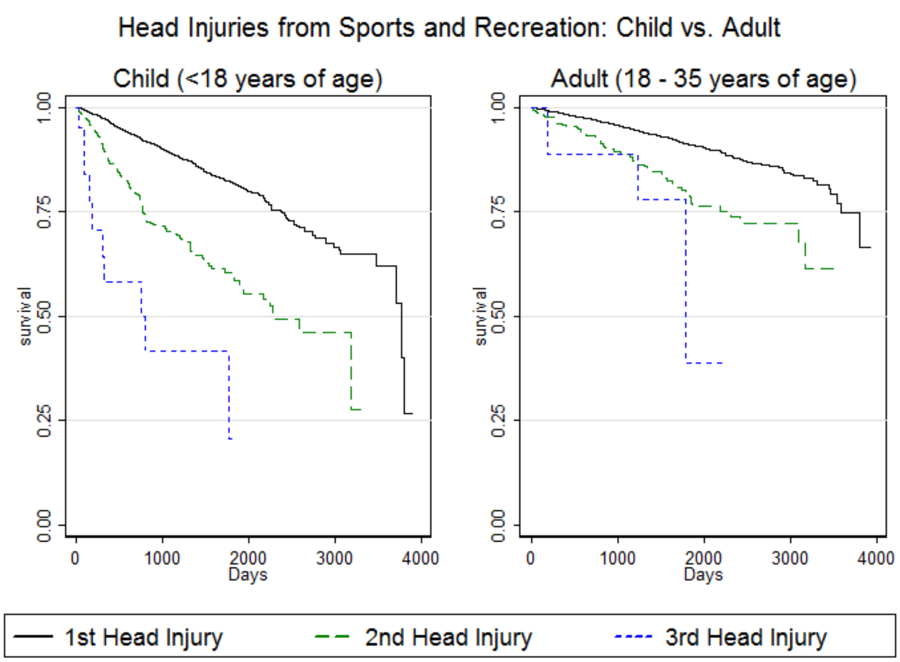

Figure 4.3 KM Time-to-event Functions by Observed History of SR Head Injury Treated in an Emergency Department:<18 years vs. 18 - 35 years

The median time to head injury for those at risk a second or third head injury was 3,179 days (8.7 years) and 1,760 days (4.8 years), respectively. The median time to head injury for those with no previous SR head injury was approached at 3,938 days of follow-up (10.78 years). The probability of not sustaining a head injury at one year of follow-up was 98%, 91%, and 68% for those with no previous, one, and two previous head injuries, respectively. At six years of follow-up, the probability of not sustaining a head injury was 84%, 64%, and 30% for those with no previous, one, and two previous head injuries, respectively.

Time to head injury for males was significantly shorter than females (χ^2 = 3.90, p = 0.0482); although, no significant differences were observed between time to head injury for males and females when stratified by number of head injuries observed (0 previous HI: χ^2 = 3.63, p = 0.0568; 1 previous HI: χ^2 = 0.23; p = 0.628; 2 previous HI: χ^2 = 0.20, p = 0.656). For children less than 18 years of age, time to head injury was significantly shorter than for adults 18 – 35 years of age (χ^2 = 145.72, $p < 0.0001$). When stratified by the number of head injuries observed, time to head injury occurred sooner for those who were less than 18 years of age, compared to those aged 18 – 35, who had no previous head injury (χ^2 =107.63, $p < 0.0001$) and one previous head injury (χ^2 = 35.18, $p < 0.0001$), but no significant differences were observed for those with 2 previous head injuries (χ^2 = 3.38, p = 0.066).

The results from the Cox regression are presented in Table 4.3. A global test of the proportional hazard assumption indicated the model did not violate the PH assumption ($\chi^2 = 14.65$, df = 9; p = 0.10). After adjusting for sex and age group, individuals observed to have one previous head injury from SR were 2.62 time more likely (95% CI: 2.23, 3.07) to sustain a head injury, while those who had sustained two previous head injuries from SR were 5.94 times more likely (95% CI: 3.43, 10.29) to sustain a head injury compared to individuals without a previous SR head injury. Males who presented to the EDs with SR injuries were 1.28 times more likely (95% CI: 1.09, 1.50) to sustain a head injury from SR than females. Compared to those 30 – 35 years of age, those aged 7 – 13, 14 – 17, and

Table 4.3 Cox Proportional Hazard Model: Main Analysis

Variable	HR	Robust SE	P-Value	95% CI	
Sex					
Male	1.28	0.10	**0.002**	1.09	1.50
Female*	Reference	-	-	-	-
Age					
< 6	2.67	1.66	0.112	0.79	9.00
7 - 13	4.29	1.05	**< 0.001**	2.65	6.92
14 - 17	4.07	0.97	**< 0.001**	2.56	6.49
18 - 22	2.05	0.50	**0.003**	1.27	3.30
23 - 26	1.46	0.40	0.160	0.86	2.49
27 - 30	1.46	0.43	0.201	0.82	2.61
30 - 35*	Reference	-	-	-	-
Previous HI					
1	2.62	0.21	**< 0.001**	2.23	3.07
2	5.94	1.66	**< 0.001**	3.43	10.29
0*	Reference	-	-	-	-

* Reference

18 – 22 were observed to be significantly more likely to sustain a head injury from SR.

While the main analysis removed subsequent observations that occurred within a 14 day period for the same unique identifier, a sensitivity analysis was performed to observe how the data were affected by removing observations that occurred within 60 days of a previous observation (Table 4.4). The sensitivity analysis showed small changes from the model that removed observations occurring within 14 days (Table 4.3); however, none of the variables changed in significance, and the hazard ratios did not change dramatically.

Table 4.4 Cox Proportional Hazard Model: Sensitivity Analysis

Variable	HR	Robust SE	P-Value	95% CI	
Sex					
Male	1.30	0.11	**0.001**	1.11	1.53
Female*	Reference	-	-	-	-
Age					
< 6	3.00	1.87	0.078	0.88	10.19
7 - 13	4.34	1.09	**< 0.001**	2.65	7.10
14 - 17	4.15	1.01	**< 0.001**	2.57	6.69
18 - 22	2.01	0.51	**0.005**	1.23	3.30
23 - 26	1.51	0.42	0.136	0.88	2.61
27 - 30	1.40	0.43	0.276	0.77	2.55
30 - 35*	Reference	-	-	-	-
Previous HI					
1	2.55	0.22	**< 0.001**	2.16	3.01
2	5.32	1.73	**< 0.001**	2.81	10.07
0*	Reference	-	-	-	-

Note: No observations within 60 days of previous ED visit
*Reference

The results of the logistic regression model that provides estimates for the odds of sustaining a head injury by SR activity are presented in Table 4.5. After adjusting for age group, sex, and previous head injuries, the activities that significantly increased the odds of sustaining a head injury for those who presented to an ED with a SR related injury were animal related activities (OR = 3.54; 95% CI: 2.84, 4.40), rugby (OR = 2.57; 95% CI: 2.15, 3.06), OHV/ATV (OR = 2.17; 95% CI: 1.84, 2.56), hockey (OR = 1.98; 95% CI: 1.79, 2.20), cycling (OR = 1.93; 95% CI: 1.73, 2.17), skiing/snowboarding (OR = 1.44; 95% CI: 1.28, 1.62), and football (OR = 1.42; 95% CI: 1.23, 1.63). Activities which significantly decreased the odds of presenting with a head injury were basketball (OR = 0.38; 95% CI: 0.31, 0.46), (OR = 0.81; 95% CI: 0.69, 0.94), skateboarding/ rollerblading (OR = 0.80; 95% CI: 0.69, 0.93), and soccer (OR = 0.85; 95% CI: 0.75, 0.96).

Table 4.5 Logistic Regression: Odds Ratio for Head Injury from SR Activities

Variable	**Odds Ratio***	**Robust SE**	**P-value**	**95% CI**	
Animal related	3.54	0.39	**< 0.001**	2.84	4.40
Rugby	2.57	0.23	**< 0.001**	2.15	3.06
OHV /ATV	2.17	0.18	**< 0.001**	1.84	2.56
Hockey	1.98	0.10	**< 0.001**	1.79	2.20
Cycling	1.93	0.11	**< 0.001**	1.73	2.17
Skiing/snowboarding	1.44	0.09	**< 0.001**	1.28	1.62
Football	1.42	0.10	**< 0.001**	1.23	1.63
Baseball/softball	0.92	0.10	0.416	0.74	1.13
Soccer	0.85	0.05	**0.008**	0.75	0.96
Playground equipment	0.81	0.06	**0.007**	0.69	0.94
Skateboarding/rollerblading	0.80	0.06	**0.003**	0.69	0.93
Basketball	0.38	0.04	**< 0.001**	0.31	0.46
Other Sports and Recreation**	Reference	-	-	-	-

*Adjusted for age group, sex, and number of head injuries
**Reference

4.4. Discussion

This study is one of the first Canadian studies to investigate, the duration between subsequent head injuries occurring in sport and recreation and the odds of sustaining a subsequent head injury from sports and recreation if a previous history of head injury exists. The results indicated that as the number of SR head injuries sustained increased, the duration between subsequent SR head injuries decreased. In this study, the median duration between sustaining a first and a second head injury (613 days) was more than 1.5 times the duration observed in the National Football League (NFL).(40) This can likely be explained by professional athletes being exposed to more blows to the head and to greater forces more often than what would be expected in this study's population.

The log-rank test for equality of survivor functions indicated significant differences in the number of days until head injury if a previous head injury existed. For individuals who had a history of two SR head injuries the probability that they would sustain a subsequent head injury within one year of their previous head injury was 32%, while the probability that individuals with one previous head injury and no previous head injury would sustain a head injury within one year of follow-up was 9% and 2.5%, respectively.

The use of a Cox Proportional Hazard Model allowed for the computation Hazard Ratio, which is the instantaneous relative risk as the analysis accounts for time. The regression model indicated that after sustaining one head injury from SR, individuals were 2.62 times more likely to sustain a subsequent head injury from SR than individuals who presented to an ED without a head injury. Individuals who had a history of two previous head injuries from SR were 5.94 times more likely to sustain a subsequent head injury than individuals without a SR head injury.

Although the Cox Proportional Hazard Model accounts for time (days between head injuries), it does not account for the frequency of exposure or the duration exposed to SR activities. For this reason, comparisons between other studies on subsequent head injuries from SR are difficult to make—as most studies of SR injuries have a measure of exposure or time at risk of injury (athlete-exposures (games/practices/training sessions), the number of player-game hours (the duration of the game/practice)) it is it not possible to determine how many SR events or the duration of SR participation any of the individuals in this study were exposed to. Nevertheless, the results of the present study do follow the general pattern of results that sustaining a head injury increases the risk for future head injury in SR activities. (8,17-25)

Although it was not possible to establish what recommendations for return to play, if any, were given to individuals who sustained a head injury, the results from the sensitivity analysis showed that even after removing observations that occurred within approximately 2 months (60 days) of a previous injury, those with a previous history of one or two head injuries were still more than 2.5 and more than 5 times more likely to sustain another head injury, respectively. Therefore, the exclusion of observations within the 14 day cut-off period is likely a sufficient duration to ensure that the observations were different acute injuries, rather than repeat presentations for the same injury event.

The proportion of males presenting with head injuries from SR (77%) was slightly greater in this study than the 71% reported previously in Edmonton.(41) While females are reported to have a greater risk of severe injury in comparable activities in which both females and males participate, (42-44) after adjusting for SR activity, age group, and previous head injuries, males were 28% more likely to sustain a SR head injury than females. These findings quantify the increased risk of SR head injury for males, while supporting the general findings of Bloom et al.(26) who report that male university athletes sustained significantly more concussions than female athletes, and Kelly et al.(32) who reported significantly higher rates of SR head injury for males 10 – 35 years of age. Although a previous Alberta study of high-school students' participation in sport (45) indicated no significant difference in the odds of sustaining a concussion between males and females ($OR_{females}$ = 0.79; 95% CI: 0.58, 1.06), the findings of the present study indicates a similar, yet significant reduction in risk for females.

While the majority of research on subsequent head injuries has focused on professional, college, and high-school athletes, our results indicated that individuals between 7 – 13 and 14 - 17 years of age had the greatest hazard ratios for sustaining a head injury due to SR activities when presenting to the ED. Additionally, of those who sustained three head injuries, 77% (10/13) were less than 18 years old. Considering these results, there is little research on subsequent head injuries and cumulative effects of head injuries for the age groups that have the greatest hazard of head injury from SR.

Compared to other SR activities, the SR activities that significantly increased the odds of head injuries were animal related activities, rugby, OHVs/ATVs, hockey, cycling, skiing/snowboarding/sledding, and football. Although many of these SR activities are non-contact activities, this should not be surprising as these activities also expose the participants to the greatest forces. Surprisingly, although research indicates that head injuries commonly occur in soccer at various levels of competition,(21,22,46-51) participation in soccer significantly decreased the odds of head injury.

Limitations

A number of limitations exist for this study. First, it is not possible to ascertain whether head injuries seen in the ED were indeed a first, second, or third head injury, or if other head injuries were sustained between the ED visits for these observed head injuries. Second, adults may be under-represented in this study as adults may be less likely to be brought to an ED than children. For instance, adults may not seek treatment for a head injury at an ED (or elsewhere) because they may regard the head injury as minor or decide to 'tough it out' while a child may be taken by a concerned parent.

Third, the rates of head injury per athletic-exposure (AE) or player-game hours (PGH) were not possible to calculate as the amount of time participating in SR activities is not documented in the ACCS. Also, due to the assumptions of the Cox Proportional Hazard Model, it was not reasonable to believe that the activity associated with their injury presentation was the only activity that was participated in while at risk for a first, second, or third head injury. The logistic regression model was an attempt to indicate which activities were associated with head injuries presenting to an ED.

Finally, administrative data are limited to ED presentations only; therefore it was not possible to ascertain recovery time or time until returning to activities. The exclusion of observations for the same individual within a period of 14 days and the sensitivity analysis which excluded observations within 60 days was an attempt to control for injuries which may physically prevent participation in SR (fractured limbs), and to remove observations that were separate ED presentations for the same injury. However, it was not possible to determine if individuals had fully recovered from their previous head injury, prior to sustaining a subsequent head injury.

Strengths

Through the use of a health care administrative database, this study was able to identify all head injuries that presented to an ED in the City of Edmonton, Alberta. While other studies have solely investigated subsequent head injuries occurring in players participating in specific sports, this study was able to identify subsequent head injuries from a number of sports and recreational activities. The eleven years of data provided a sufficient duration to follow multiple individuals, who may or may not frequently participate in SR activities, to adequately investigate subsequent head injuries in a population based sample.

4.5. Conclusion

The results of this study provide further evidence of subsequent head injuries occurring in sports and recreation activities. While previous research of subsequent SR head injuries has focused almost exclusively on football, soccer, rugby, and hockey,(8,17-25,27,52) head injuries from a wide variety of sports and recreation activities were included in this study. It is important to note that the time between head injuries significantly decreased as the number of head injuries observed increased, and at one year of follow-up the probability of sustaining a subsequent head injury increased from 2.5% for those with no previous head injury to 32% for those with 2 previous head injuries.

While sustaining a head injury appears to vary by the SR activity engaged in, the results of this study indicate that at the population level, males are nearly 30% more likely to sustain a head injury in SR than females. This study also identified that teenagers and young children were most likely to sustain a SR related head injury. Limited research exists for children aged less than 13 years of age, and further investigation is warranted, specifically to the long term affects of subsequent head injuries on children whose brains are still developing. Programs designed to monitor return-to-play and injury prevention after a SR head injury appear to be warranted specifically in the younger age groups in order to further understand factors that may influence subsequent head injuries from SR.

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Chapter 5

Discussion & Future Directions

5.1. Discussion

The introductory chapter of this thesis outlines the rational, objectives, and significance of the studies presented in chapters 3 and 4. The following discussion reiterates the results of this thesis and the significance of the findings.

The second chapter summarized aspects of sport and recreation-related head injuries and provides an extensive review of literature for head injuries occurring in sports and recreation and subsequent or recurrent head injuries sustained in sports and recreation. Methodological issues that inherently plague SR head injury research include variations in definitions, difficulties in identification, under-reporting of symptoms, and wide spread differences in post-head injury management. The highest rates of head injury are commonly reported in contact sports such as hockey, football, and rugby (1-17); however, these rates vary by level of play (e.g., high school, collegiate, professional) and by sex. It was also identified that a head injuries occurring from equestrian activities, cycling, off-highway vehicles, and skiing/snowboarding maybe of greater severity, including a number fatalities.(18-25)

Furthermore, it was recognized that 17% – 74% of head injuries presenting to EDs are not due to organized sports, but rather general recreation and leisure activities.(26-29) Whether males or females are more likely to sustain a head injury appears to vary by activity,(30) yet males account for the highest proportion of SR HI treated in EDs or hospitalized,(29,31) and have higher overall rates of SR head injury than females.(27,32) Individuals with a prior history of SR head injury are reported to have an increased risk of subsequent head injury by 1.4 – 11.1 times,(5,10-12,33-38) while 1% – 24% of athletes sustain a subsequent head injury within the same athletic season.(10,17,33) The majority of research on subsequent SR head injuries has focused on competitive athletes at the high school, college and professional levels, and are almost exclusively limited to the sports of hockey, football, soccer, and rugby.(5,10-12,16,17,33-41)

The third chapter provides a descriptive analysis of the epidemiology of head injuries occurring in sports and recreation to head injuries from non-sport related activities that presented to EDs in Edmonton, Alberta. Sport and recreational head injuries accounted for nearly 40% of the head injuries observed. Similar to previous research,(28,31,32,42,43) males accounted the majority (69%) of the SR head injuries that presented to an ED; however, females were observed to be more likely to present with SR head injuries from baseball, basketball, and soccer which is supports previous findings.(44-46) Interestingly, females were also more likely than males to present to an ED with a head injury from skiing/snowboarding, rugby, playground equipment, and the broader category of other SR activities.

Although the SR activities that contribute to head injuries vary, previous reports have also observed a limited number of SR activities contribute to the majority of SR head injuries.(27,32,47,48) Local injury prevention initiatives need to focus on the five activities of hockey, cycling, skiing/snowboarding, soccer, and football, which together accounted for 59% of SR head injuries. Such initiatives need to include increasing helmet usage for cyclists and skiers/snowboarders.

Although children commonly account for a large percentage of SR injuries presenting to EDs (32,42,49,50) or admitted to hospital,(42,51) the fact that 70% of SR head injuries occur to children less than 18, appears to be higher than other studies. While simple comparisons between studies are problematic due to various age groups used, this does suggest further research is required.

In the fourth chapter of this thesis, Kaplan-Meier survival curves and the median duration between observed head injuries from SR were presented, as well as a Cox Proportional Hazard model. The Cox model indicated the hazard ratio for sustaining a subsequent head injury from SR activities when presenting to an ED are 2.62 and 5.94 times greater for those with a history of one and two previous SR-related head injuries. While increased risk is comparable with previous findings,(5,10-12,33-38) this study is one of the first to use time-to-event modeling for SR head injuries. The results of this study may also be more generalizable to the broader population than much of the current literature, due to its population based approach.

Although others have reported that SR related head injuries sustained by children account for the largest proportion of the head injuries for children 9 - 18 years of age,(32,52,53) the finding that the children 7 – 13 and 14 – 17 year olds had the greatest risk of SR head injury is alarming. Combined with the above finding that a history of SR head injury increase the risk of a subsequent head injury, the potential for multiple head injuries at such an early age needs to be addressed.

The SR activities that significantly increased the odds of a head injury were animal related activities, cycling, football, hockey, OHVs/ATVs, rugby, and skiing/snow-boarding/sledding. For example, individuals who presented to an ED with an injury that occurred while participating in one of these SR activities, such as horseback riding (animal related), were significantly more likely to have at least one injury diagnosis of a head injury, compared to other SR activities. Consistent with the literature, these activities are commonly associated with high rates of head injuries. Interestingly, despite numerous head injuries reported in soccer and basketball, participation in basketball (OR = 0.38; 95% CI: 0.31, 0.46) and soccer (OR = 0.85; 95% CI: 0.75, 0.96) significantly decreased the odds of sustaining a head injury; however, it is unclear why these activities were not positive predictors of head injuries.

5.2. Methodological Issues

While previous studies have likely captured a high percentage of the head injuries that are actually sustained due to the use of direct observation,(3,4,6,8,10,13,15,33,36,37,54-64) such studies usually focus on a specific team sport. Although beneficial for sport-specific information, the results of these studies are difficult to generalize to the general population. Studies using surveys to investigate head injuries occurring in SR are also common,(5,8,11,30,34,35,38) however studies utilizing surveys may be influenced by recall and volunteer bias, and may also introduce unqualified injury diagnoses. Without a definitive definition of head injury that both researchers and clinicians agree upon, all studies are susceptible to variations in such injury diagnoses.

The studies in chapters 3 and 4 used an administrative health data base to investigate sport and recreation related head injuries over a period of 11 fiscal years (1997/98 – 2007/08). Although these studies aimed to capture as many SR related head injuries as possible, it is certain that many head injuries that occurred in the Edmonton region from 1997 – 2008 were not identified because they were not treated in an ED. Despite this, due to the length of the follow-up, the studies presented in chapters 3 and 4 provide valuable information to the utilization of ED health services for SR head injuries over an 11 year period. Although some American studies have utilized injury an surveillance system to report on SR injuries occurring since 1988,(4,13,55-63) these studies do not report follow-up on the same individuals, whereas this thesis identifies presentations to all five ED in Edmonton for the same individuals throughout the follow-up. Also, while the results of this thesis may be generalizable to other Canadian cities, it may not be generalizable to the American population; since Canada has a universal health care system, less severe head injuries may have presented in greater frequency that what may be seen in the United States.

While the GCS has been commonly used to identify head injuries presenting to EDs due to SR,(26,28,29,52) the GCS was not available in the ACCS database. For that reason, it was not possible to directly compare the severity of head injuries in these studies, as measured by the GCS, with other published works. Nevertheless, through proxy measures such as triage and disposition severity may be approximated.

Injury diagnoses have previously been used to identify head injuries occurring in SR. Yang et al.(31) used the primary diagnosis field to identify head cases of hospitalized concussions, while Kelly et al.(32) used the first two diagnosis field to investigate severe head injury from SR. Since all 10 diagnosis fields were searched to identify head injuries for chapters 3 and 4, some of head injuries that presented to the EDs may have been less severe than the head injuries reported in comparable studies, but all head injuries documented in the ACCS were captured. Also, since 92.8% of the SR head injuries identified in chapter 3 were identified by the primary diagnosis field, it is unlikely that the use of all 10 diagnosis fields significantly influenced the results.

The use of ICD-9 external cause codes has also been used in other studies to identify SR related injuries,(31,42,51) but external cause codes used to identify sport related injuries are generally limited to a few ICD-9 codes (E886.0, E917.0, E917.5, E927.0).(31,42) The studies presented in chapters 3 and 4 include a wide range of ICD-9 and ICD-10 external cause codes in order to identify recreational activities (most notably ICD-9 codes of: E885.0 – E885.4, falls from non-motorized scooters, roller skates, skateboard, skis, snowboard; E910.0 – E910.2, accidental drowning and submersion while water-skiing, while engaged in other sport or recreational activity with/without diving equipment; E849.4, accident in recreation area). The sport and recreation coding system within the ACCS is of great advantage in identifying SR related injuries. With more than 136 different SR codes, there were 4,200 SR injuries (85%) identified in the ACCS for the analysis in chapter 3, while the supplementary search of ICD-9 and ICD-10 codes identified an addition 750 SR injuries (15%) that were not originally attributed to SR.

Despite these differences with previous works investigating SR head injury with administrative health data, the studies presented in chapters 3 and 4 are not without limitations. For instance, the majority of minor or less severe head injuries may not have sought medical treatment at an ED. Also, any errors in documentation or coding will also have influenced the data presented. However, the results obtained are likely equivalent to what would be observed in other large Canadian cities using the same methods for SR injuries that present to EDs.

5.3. Future Directions

The results presented in chapter 3 found that individuals 14 – 17 and 7 – 13 years of age had the highest rates of head injury for SR injury diagnoses presenting to EDs (12.62/1,000 and 11.49/1,000, respectively). Overall, males were 1.25 times more likely to present to an ED with a SR head injury than females, and were also more likely to sustain a head injury from the activities of football (OR = 9.85), hockey (OR = 4.54), and cycling (OR = 1.49). However, males were less likely to sustain SR head injuries from participating in skiing/snowboarding (OR = 0.72), rugby (OR = 0.53), playground equipment (OR = 0.50), baseball (OR = 0.50), basketball (OR = 0.47), soccer (OR = 0.45), animal related activities (OR = 0.10), and in other SR activities (OR =0.72). The results presented in chapter 4 found that individuals with one or two previous head injuries from SR were 2.62 and 5.94 times more likely to sustain a subsequent head injury from SR, respectively, compared to individuals with no previously observed SR head injury.

Those who sustain multiple head injuries may be negatively affected in work, educational, and social environments. Head injuries negatively affect cognitive processing speed, verbal and visual memory, planning skills, and reaction time (65-70) and symptoms such as headache, fatigue, sleep disturbances, increase irritability, poor concentration, and depression can persist from 1 – 12 months post head injury.(26,71) Since the highest rates of SR head injury were observed for children 7 – 17 years old, there is cause for concern that head injuries in a young population may significantly affect their quality of life.

Also, an increased risk of subsequent head injury may also adversely affect the overall health care system. Multiple head injuries from SR are reported to increase the risk for a diagnosis of mild cognitive impairment, depression, and Alzheimer’s disease later in life,(33,72,73) and an increased risk of subsequent head injury has been shown exist for those with a previous head injury from

SR.(5,10-12,33-38) As a prior history of one and two SR head injuries increased the odds of subsequent SR head injury by 2.62 and 5.94 times, respectively, and SR head injuries were most likely to be seen for children 7 – 17 years of age, there is evidence that children are at risk of multiple head injuries in both sports and recreational activities.

Policy changes should be addressed particularly at the recreational level. The Canadian Medical Association and various SR organizations need to develop, implement, and mandate guidelines for the education of players, coaches, staff, and volunteers. Organizations and governments may also need to implement a strict policy of medical evaluation and clearance prior to allowing athletes who sustained head injuries to return. Children and adults, parents and players, everyone involved in sports and recreation need more education about the consequences of multiple head injuries. Recently, the American States of Washington, Oregon, and Texas have passed return-to-play legislation in an effort to reduce head injuries, while a number of States are considering implementation of similar laws.(74,75)

Future studies on SR head injuries may benefit from the use of administrative databases to investigate health care utilization for conditions which require extended periods of follow-up. Examples of such conditions include Post-Concussion Syndrome, Depression, and Alzheimer’s disease. Future research may also examine recommendations provided by health care providers regarding head injuries, as well as whether players, parents, coaches, teams, and organizations adhered to recommendations. Studies that aim to evaluate the efficacy of various return-to-play (RTP) guidelines are also warranted. As there is no current “gold standard” for the management of SR head injuries, investigating RTP protocols which are already in place at various institutions may provide evidence needed to implement a clinically evaluated RTP protocol.

There also needs to be an increased focus on SR head injuries in the younger pediatric population. The effect of multiple head injuries on developing children needs to be addressed, due to the long lasting effects of head injuries. Prospective studies using physician billing along with ED and hospitalization data should be embarked on to further investigate not only time-to-subsequent head injury, but also to investigate the possibility of increased severity of head injury with subsequent SR head injuries. Also, the investigations regarding utilization of health-care for post-concussive symptoms, depression, and other conditions may be warranted. Finally, qualitative studies may need to investigate perceptions of head injuries occurring in sports and recreation, risk perception, physicians beliefs about RTP guidelines, and reasons why individuals may return to competition prior to resolution of symptoms or prior to obtaining medical clearance.

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Appendix A: ACCS SR Activity Codes

Ambulatory Care Classification System Sport and Recreation Codes and Descriptions	
ACCS SR-Code	**ACCS Sport and Recreation code Description**
1	Aerobics
2	Aircraft - Recreational Motorized (e.g. fixed-wing)
3	Aircraft - Recreational Non-Motorized (e.g. glider)
4	ATV - 3 Wheel
5	ATV - 4 Wheel (default)
6	ATV - Four Wheel Drive
7	ATV - Front Wheel Drive
8	ATV - Rear Wheel Drive
9	Amusement Rides
10	Auto Racing
11	Badminton
12	Baseball (hardball, softball, T-ball, slo-pitch)
13	Basketball
14	Baton Twirling
15	Billiards/Pool/Shuffleboard
16	BMX Cycling (organized bicycle racing on a dirt track sport type bicycle)
17	Boating - Motorized
18	Boating - Canoe
19	Boating - Kayak
20	Boating - Sailing
21	Boating - Windsurf/Sailboard/Kiteboarding (wind)
22	Boating - Waverunner
23	Boating - Water Ski-Doo
24	Boating - Other (default)
25	Boxing/Kickboxing/Capoeira/Punch Bag
26	Bowling (5 or 10 Pin)
27	Cricket
28	Croquet/Lawn Bowling/Bocci Ball/Bocce Ball/Petanque
29	Curling
30	Cycling - Driver (street/highway and not spec. driver or passenger.) (Does not include mountain biking/motorcycle/dirt bike)
31	Cycling - Passenger (street/highway) (Does not include mountain biking/motorcycle/dirt bike)
32	Cycling - Unicycle
33	Dancing
34	Dirt-biking/Minibikes/Motorcross
35	Diving/Snorkeling

36	Fencing
37	Fishing
38	Football
39	Frisbee/Ultimate Frisbee
40	Go-Carting
41	Golf
42	Gymnastics (Competitive/Organized)
43	Handball
44	Hang-Gliding/Para-Sailing
45	Hiking
46	Horseback Riding/Jumping/Show Jumping (Competitive/Recreational)
47	Hockey - Ice (default)
48	Hockey - Street/Ball
49	Hockey - Field/Floor
50	Hockey - Inline
51	Hunting - Gun (default)
52	Jogging/Running
53	Lacrosse
54	Lawn Darts
55	Luge/Bobsled
56	Martial Arts (Judo, Kendo, Karate, Tai Chi, etc.)
57	Mountaineering/Rock Climbing/Ice Climbing (Indoor/Outdoor)
58	Playground Equipment - Swings
59	Playground Equipment - Slides
60	Playground Equipment - Monkey Bars
61	Playground Equipment - Teeter Totter
62	Playground Equipment - Merry-Go-Round
63	Playground Equipment - Platforms > 4 Feet
64	Playground Equipment - Sliding Poles
65	Playground Equipment - Other (default)
66	Play Not Further Specified (unstructured play: running/jumping/cartwheel/skipping)
67	Racquetball
68	Ringette
69	River Rafting
70	Rugby
71	Scuba Diving
72	Shooting - Gun (includes; target, rifle range, skeet, BB, pellet)
73	Skateboarding
74	Skating - Figure Skating
75	Skating - Ice Skating (default)

76	Skating - Inline (Rollerblading)
77	Skating - Rollerskating/Wheely/Heely Shoes
78	Skating - Speed Skating
79	Skiing/Snowboarding/Skiboards/Skiblades/Recreational Downhill (default)
80	Skiing - Racing Downhill (organized events like downhill, slalom, parallel)
81	Skiing - Cross Country
82	Ski Jumping (organized event done off a formal measured platform, aerials)
83	Sky Diving/Parachuting/Bungee Jumping
84	Snowboarding/Snowskating
85	Snowmobiling - Driver (default)
86	Snowmobiling - Passenger
87	Snowmobiling - Towed Behind on Toboggan, Tube, Sleigh
88	Soccer
89	Squash
90	Swimming - Pool (competitive/recreational)
91	Swimming - Lake
92	Swimming - River
93	Swimming - Pond
94	Swimming - Other (default)
95	Swimming - Wading Pool (includes fountains, water amusements, backyards)
96	Table Tennis
97	Tennis
98	Tobogganing/Sledding/Snow Tubing
99	Track and Field
100	Trampoline
101	Triathlon/Biathlon
102	Volleyball
103	Walking (for Exercise)
104	Walleyball
105	Waterpolo
106	Waterskiing/Tubing/Wakeboarding/boarding/Trick Skiing (pulled by motor boat)
107	Water Sliding
108	Weightlifting/Weight Training
109	Wheelchair Sports
110	Wrestling (competitive/play)
111	Observer of Sporting Event
112	Other (e.g. Hacky Sack, Cliff Jumping, Surfing, Demolition Derby)
113	Chuck Wagon Racing
114	Non-motorized scooter
115	Pocket/Rocket/Mini-Moto Bikes

116	Yoga
117	Exercise - including exercise, exercise ball/equipment, training, circuit training, working out
118	Physical Education/Gym Class (formal school programs - excludes Cheerleading)
119	Lazer Tag
120	Paint Ball
121	Mountain Biking
122	Mountain Boarding
123	Broomball
124	Dodgeball
125	Kickball/Wall Ball
126	Cheerleading
127	Videogaming

Appendix B: Sport and Recreation Activity Groupings

Sport and Recreation Activity Groupings by ICD-9, ICD-10, and ACCS SR Activities			
Sport and Recreation Activity	**ICD-9-CM**	**ICD-10-CA**	**ACCS Coded Activities**
Animal Riding/Rodeo/Animal-drawn Vehicle	E8105, E8115, E8125, E8135, E8145, E8155, E8165, E8175, E8185, E8195, E8205, E8215, E8225, E8235, E8245, E8255, E8262, E8272, E8282, E8292, E8263, E8273, E8283, E8293	V800, V802, V801, V80, V803, V804, V805, V806, V807, V808, V809	Chuck wagon racing, horseback riding/jumping, show jumping
Baseball/Softball/Cricket	--	W2101, W2205, W5105	Baseball, tee-Ball, slow pitch, soft ball, cricket
Basketball	--	--	Basketball
Cycling/BMX	E8003, E8013, E8023, E8033, E8043, E8053, E8063, E8073, E8106, E8116, E8126, E8136, E8146, E8156, E8166, E8176, E8186, E8196, E8206, E8216, E8226, E8236, E8246, E8256, E8261, E8271, E8281, E8291	V10, V100, V101, V102, V103, V104, V105, V109, V11, V110, V111, V112, V113, V114, V115, V119, V12, V120, V121, V122, V123, V124, V125, V129, V13, V130, V131, V132, V133, V134, V135, V139, V14, V140, V141, V142, V143, V144, V145, V149, V15, V150, V151, V152, V153, V154, V155, V159, V16, V160, V161, V162, V163, V164, V165, V169, V17, V170, V171, V172, V173, V174, V175, V179, V18, V180, V181, V182, V183, V184, V185, V189, V19, V190, V191, V192, V193, V194, V195, V196, V198, V199	Cycling, cycling passenger, unicycle, BMX, mountain biking
Football	--	W5103, W2203	Football

Sport and Recreation Activity Groupings by ICD-9, ICD-10, and ACCS SR Activities (continued)			
Sport and Recreation Activity	**ICD-9-CM**	**ICD-10-CA**	**ACCS Coded Activities**
Hockey	--	W5102, W2103, W2102, W2202	Hockey, ringette, roller hockey, field/floor hockey, street/ball hockey
OHV/ATV/Snowmobile/ Motorbike	E8200, E8201, E8202, E8203, E8210, E8211, E8212, E8213, E848	V200, V210, V220, V230, V240, V250, V260, V270, V280, V201, V211, V221, V231, V241, V251, V261, V271, V281, V202, V212, V222, V232, V242, V252, V262, V272, V282, V290, V86, V860, V8600, V8608, V861, V8610, V8618, V862, V863, V8630, V8638, V864, V865, V8650, V8651, V8658, V866, V8660, V8661, V8668, V867, V869, V8690, V8691, V8698	ATV, snowmobile, dirt bike, motor cross, towed behind snowmobile on toboggan, pocket/rocket/mini-moto bikes, auto racing, go carting
Playground Equipment	E8840	W09, W0901, W0902, W0903, W0904, W0905, W0908, W0909	Play ground equipment, sliding poles, fall from playground platforms > 4 feet, merry-go-round, teeter totter, monkey bars, slides, swings, trampoline
Rugby	--	--	Rugby
Skating/Skateboarding/ Scooter	E8850, E8851, E8852	W0200, W0202, W0203	Skate boarding, mountain boarding, non-motorized scooter, roller skates/wheely/heely shoes, rollerblading, ice skating, figure skating, speed skating
Skiing/Snowboarding/ Tobogganing	E8853, E8854, E847	W0204, W0201, W5101, W5100, W2201, W2200	Snowboarding/ Snow skating, Ski Jumping – organized event, Cross Country Skiing, Downhill skiing – race event, Skiing/snowboarding/ ski boards/ski blades, Tobogganing Sledding Snow Tubing, Luge/Bobsled

Sport and Recreation Activity Groupings by ICD-9, ICD-10, and ACCS SR Activities (continued)

Sport and Recreation Activity	ICD-9-CM	ICD-10-CA	ACCS Coded Activities
Soccer	--	W2204, W5104	Soccer
Occurring in Other Sports /Recreation /Leisure	E8405, E8406, E8407, E8415, E8416, E8417, E8425, E8426, E8427, E8435, E8436, E8437, E9092, E9020, E9100, E8300, E8310, E8320, E8330, E8340, E8350, E8360, E8370, E8380, E8301, E8311, E8321, E8331, E8341, E8351, E8361, E8371, E8381, E8303, E8313, E8323, E8333, E8343, E8353, E8363, E8373, E8383, E8304, E8314, E8324, E8334, E8344, E8354, E8364, E8374, E8384, E8830, E8305, E8315, E8325, E8335, E8345, E8355, E8365, E8375, E8385, E9101, E9102, E9103, E9108, E9109, E9022	W14, W15, W16, W67, W68, W69, W70, V951, V952, V958, V96, V961, V962, V963, V968, V969, X36, W94, V902, V903, V904, V905, V906, V908, V909, V912, V913, V914, V915, V916, V918, V919, V922, V923, V924, V925, V926, V928, V929, V932, V933, V934, V935, V936, V938, V939, V942, V943, V944, V945, V946, V948, V949, V907, V917, V927, V937, V947	Sky diving/parachuting/bungee Jumping, hang gliding/ parasailing, non-motorized recreational aircraft, motorized recreational aircraft, badminton, table tennis, lawn darts, billiards/pool/shuffle board, croquet/ lawn bowling/bocce ball, bowling, fishing, kick ball/wall ball, handball, walley ball, dodge ball, frisbee, wheel chair sports, hacky sack, cliff jumping, fencing, amusement rides, video gaming, observer of sporting event, boating, ski-doo, wave-runner, wind surf/sail board/kite boarding, sailing, kayak, canoe, motor boat, river rafting, water skiing/tubing/wake boarding/ boarding, lacrosse, broom ball, boxing/kick boxing/capoeira/punching bag, martial arts, wrestling, aerobics, triathlon/biathlon, track and field, yoga, school phys. ed., exercise, walking for exercise, weight-lifting, jogging/running, golf, baton, cheerleading, dance, gymnastics, mountaineering/rock climbing/ice climbing, hiking, play not specified, tennis, racquet ball, squash, swimming, water polo, diving/snorkeling, scuba diving, water sliding, volley ball, other