University of Alberta

Baseline Concussion Assessment in Varsity Athletes: A Comparison Between Two Concussion Assessment Tools and Identification of Possible Risk Factors

by

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Abstract

Objectives: To compare the self-report of symptoms on two commonly used tools: Sideline Concussion Assessment Tool 2 (SCAT2), and Immediate Post-Concussion Assessment and Cognitive Test (ImPACT). To identify potential variables on ImPACT and a preseason questionnaire that might predict concussion.

Results: Eighteen "matched" symptoms were analyzed for 349 athletes. There were significant differences between 10 symptoms. Athletes who scored in the lowest 10th percentile at baseline on ImPACT for the visual memory composite score were 2.5 (95% CI 1.09 – 5.46) times more likely to suffer a concussion. Male athletes with a family history of concussion were 0.4 (95% CI 0.17-0.93) times less likely to suffer a concussion.

Conclusions: Athletes' self-report of post-concussion symptoms differed, depending on the type of concussion evaluation tool used. ImPACT may be able to identify athletes at increased risk for concussion. More research is needed on preseason screening questionnaires.

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Chapter 1

Introduction

In the past there was a paucity of objective tools to use in assessment and diagnosis of sport-related concussion. The 1st International Symposium on Concussion in Sport was held with a goal to provide recommendations for improving the safety of athletes at risk for concussion (Aubry et al., 2002). It wasn't until the 2nd International Conference on Concussion in Sport in 2004, that the Sport Concussion Assessment Tool (SCAT) was produced (McCrory et al., 2005). In 2008, the SCAT was revised to the SCAT2 at the 3rd International Conference on Concussion in Sport (McCrory et al., 2009) and most recently the SCAT3 and a new Child SCAT3 were developed at the 4th International Conference on Concussion in Sport in 2012 (McCrory et al., 2013). These instruments are freely accessible and have therefore become commonly used across many different sporting communities and by medical support staff as one tool in the overall assessment of concussion.

In addition, computerized neurocognitive or neuropsychological testing has become widely accepted as an additional instrument in the assessment of concussions. Early on, paper and pencil neurocognitive tests were used, but they were costly, lengthy and need a trained professional to administer and interpret. As a result, the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) [ImPACT Applications Inc, Pittsburgh, PA.] was developed in the early 1990s in response to the National Football League's (NFL) request to make safer decisions when returning their athletes to play (Retrieved from: http://www.impacttest.com/about/?ImPACT-Founders-6). Nevertheless, neurocognitive testing should not be used in isolation from other tools and the final return to play decision is the result of a thorough evaluation by a trained medical professional. In addition, a return to play decision after a concussion has at least been partially based on an athlete's self-report of being symptom free on both the SCAT2 and ImPACT questionnaires. As a result, this type of report is an important factor in a physician's decision, and therefore needs to be accurately stated by the athlete.

Pre-participation physical evaluations are also a time-efficient way to identify possible pre-existing risks to athletes from sporting activities. In terms of concussion, possible risk factors that may predict the potential for a future concussion include repeated concussions over time, a recent concussion, migraine, depression or other mental health disorders and dangerous style of play (McCrory et al., 2013). The number of athletes who sustain sport-related concussions each season is on the rise. If those at risk can be identified before the injury occurs, there may be ways to prevent this from happening (Hootman et al., 2007).

Currently, the Centre for Disease Control and Prevention has determined that concussions are at an "epidemic level" in the United States. Approximately 1.6 to 3.8 million mild traumatic brain injuries (TBI), including concussions, occur in the United States every year (Schatz et al., 2011). Approximately 3-8% of the visits for sport-related injuries in young athletes arriving in emergency departments in large Canadian cities are for concussion. Harris et al., (2012) reviewed hospital records from Edmonton and the surrounding area in Alberta, Canada from April 1, 1997 – March 31, 2008. They found that there were 131,210 visits for sport or recreation injuries over the ten-year span. Head injuries accounted for 8958 of these injuries (Harris et al., 2012). Emergency departments in the United States have seen a tripling in visits for concussions in the 14-19 year old age group between 1997 and 2007 (Lau et al., 2012). The incidence of concussions in high school sports is 0.24 concussions per 1000 athlete exposures. This rate is similar for male and female sports (Lincoln et al., 2011).

The consequences of concussion can be severe if not managed properly. Randolph (2011) identified the possible risks of concussion as death or permanent neurological injury, same season repeat concussion, delayed or atypical recovery and later life effects of multiple concussions or repetitive head trauma. Athletes are familiar with muscle or ligament injuries and these have good healing potential. Athletes can receive rehabilitation and if that fails, there are successful surgical interventions. However, the signs and symptoms of a sport-related concussion may be difficult to detect and treat and cannot be viewed as orthopedic injuries or treated in the same “no pain, no gain” manner (Lincoln et al., 2011). Thus, the assessment of concussion and identification of potential risk factors is of paramount concern to the sport health professional.

Statement of the Problem

The rationalization for this current study was based on the fact that the majority of varsity athletes at the University of Alberta have baseline testing completed through a paper and pencil version of SCAT2 and through computerized ImPACT. While these tools contain similar post-concussion symptom scales, they are presented in a very different way. Self-report of post-concussion symptoms, compared to an athlete's own baseline, provides the biggest change in scores from a baseline test to a post-concussion assessment (Valovich McLeod, 2009). In addition, at the time of planning this thesis, there had been no previous research published on identifying risk factors for concussion from ImPACT testing done at a baseline assessment prior to a competitive season.

Purpose of the Study

The first purpose of this study was to examine varsity athletes' self-report of symptoms during pre-season baseline testing on two commonly used assessment tools for concussion, to determine if there were any differences in reporting. The two measures were the paper and pencil version of the Sideline Concussion Assessment Tool 2 (SCAT2) (McCrory et al., 2009), and the computerized neurocognitive test Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) [ImPACT Applications Inc, Pittsburgh, PA.]. A second purpose of this study was to assess baseline composite scores from ImPACT, to determine if athletes who scored lower at baseline on any of these measures were at any greater risk for concussion during the subsequent season.

Post-concussion symptom(s) clusters from ImPACT were also analyzed. Finally, the third purpose was to possibly identify potential risk factors for concussions through a preseason concussion questionnaire (Appendix 1).

Hypotheses

Hypothesis 1: Athletes will report more post-concussion symptoms and more severe symptoms at baseline on the computerized neuropsychological ImPACT as compared to the paper and pencil version of SCAT2.

Hypothesis 2: Athletes who score at or below the lowest 10^{th} percentile on composite scores and post-concussion symptom clusters at baseline using the computerized neuropsychological ImPACT will be at greater risk for a future concussion as compared to those athletes who score above the 10^{th} percentile.

Hypothesis #3: Athletes who report more health problems at baseline on their preseason concussion questionnaire will be at a greater risk of future concussion than those athletes who do not report any problems.

Delimitations

There are a variety of methods that are used to diagnose a concussion in an athlete such as clinical assessment, self-report of symptoms, differences in cognition, postural control and neuropsychological or neurocognitive changes. These can all be assessed immediately and in follow-up after an injury. In a population of high-school athletes, self-report symptom scores were seen to increase to a greater extent than neuropsychological or balance testing scores during post-concussion follow-up (Valovich McLeod & Leach, 2012). Self-reports of symptoms are currently used with the University of Alberta varsity athletes during baseline, immediately following a concussive injury, at subsequent follow up assessments and prior to return-to-play. Two different tests are used: the SCAT2 and ImPACT, each containing a section on self-report of symptoms.

In a previous study carried out at the University of Alberta, Mrazik et al. (2012) found a significant difference in 10 of the 18 self-report symptoms of varsity athletes between the SCAT2 and ImPACT tests, as well as a significant difference in the total symptom scores (TSS). This group of athletes responded differently when self-reporting concussion symptoms, depending on the type of instrument used and the mode in which it was administered. Mrazik et al. (2012) found greater mean symptom scores on ImPACT for 13 of the total 18 self-report symptoms and for all of the 10 significantly different symptoms. In addition to this, Blake et al. (2013) found that midget and bantam ice hockey players who had SCAT2 baseline total symptom scores in the lowest 25th percentile and baseline SCAT2 total scores in the lowest 25th percentile were at greater risk of concussion. The increase in Relative Risk (RR) for bantam players was 1.54 (95% CI 1.07 to 2.20) and for midget level was 1.40 (95% CI 1.03 to 1.90) (Blake et al., 2013). Finally, Lau et al. (2011) found that there was a net increase in sensitivity of 24.41% of predicting protracted recovery (≥14 days) using neuropsychological testing and symptom clusters together at the time of injury, compared with using total symptoms alone in high school athletes (Appendix 2.0). These previous findings supported the hypotheses for this current study.

Limitations

The data from the 2010-2011 and 2011-2012 athletic seasons were reviewed retrospectively and accurate data collection was necessary. If data was missing or misclassified, due to the retrospective nature of this study, that individual athlete's results were removed from further analyses. Because of financial and personnel constraints, only athletes in contact/collision sports at the University of Alberta were tested at baseline. This meant that all athletes were not baseline tested with ImPACT at the start of every season, unless a concussion had occurred in the previous season. In such a case, that individual athlete had a new baseline test performed at the beginning of the following season.

Athletes completed the paper and pencil version of the SCAT2 at baseline at their individual team's training locations either before or after a practice. Earlier research conducted by Mrazik at al. (2013) found that an athlete's self-report of post-concussion symptom scores can increase immediately post-exertion. It is possible, in this current study, that athletes who were fatigued after a rigorous training bout may have reported more symptoms than athletes who completed baseline testing prior to the start of practice. Another limitation of the SCAT2 or ImPACT post-concussion symptom scales arises from the bias of social desirability. When a questionnaire is provided to research subjects there is a risk that social desirability may cause respondents to answer in a manner that they deem would be viewed favourably by others. This may be especially true in athletes who are highly motivated to participate and would not want to be viewed as less than fully healthy at pre-season testing.

The computerized ImPACT testing was completed in a group setting, in a computer lab, which may have led to a variety of environmental stressors. While the test was running, athletes were asked to remain quiet but there were inevitably some fidgeting and background distractions. These distractions may have had a negative influence on an athlete's baseline composite score. Athletes in this current study ranged in age from 16-28 years and it has been previously reported that high school athletes tend to perform worse on the SCAT2 at baseline as compared to university athletes (Jinguji et al., 2012). Due to the large age range in this current study, there was a discrepancy in education level and maturation level, which may have affected baseline test scores on both instruments.

The preseason concussion questionnaire used for this study was not validated, but did include known risk factors for concussion from current research (Makdissi et al., 2013). Athletes also completed this in a group setting, which again can lead to distractions. This questionnaire was not analyzed for psychometric properties, which may have created limitations in interpreting the answers. Recall bias may also have affected the recollections of the individual athlete's responses to questionnaire items leading to potentially less accurate information on an athlete's previous history.

Chapter 2

Review of Literature

Concussion Assessment Tools

The Sport Concussion Assessment Tool 2 (SCAT2) was used in this study and represents a standardized method of evaluating an injured athlete. It can be used in athletes aged 10 years and older (McCrory et al., 2009). It supersedes the original SCAT published in 2005 (McCrory et al., 2005). The SCAT2 begins with questions on the athlete's sport, age, sex and level of education. It includes a 22-item symptom evaluation, each graded on a 7 point Likert scale from 0 (no symptoms) to 6 (severe symptoms). The athlete also answers whether any of the symptoms reported get worse with physical or mental activity. Each item on the symptom inventory as well as the total symptom score (TSS) were used for data analyses in this study.

The SCAT2 continues with a Standardized Assessment of Concussion (SAC). The SAC contains orientation, immediate memory, concentration and delayed recall components. After injury, a decline in SAC score was found to be 95% sensitive and 76% specific in accurately classifying injured and uninjured athletes on the sideline (McCrea, 2001). The SCAT2 also examines an athlete`s postural stability using the Balance Error Scoring System (BESS). The BESS is a quantifiable and cost effective way to assess postural stability. Athletes perform a double leg stance, a single leg stance and a tandem stance. A score is calculated by adding 1 error point for each error made in a 20 second trial. The BESS is sensitive enough to identify balance deficits often seen in cases of concussion (Guskiewicz, 2003). An overall score is calculated after completion of the SCAT2 using a subtotal from the self-report symptom score, the balance error score and the SAC.

The computerized neurocognitive Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) version 1.0 became available in 1998 as a research instrument. The test became commercially available in 2000 for high schools and universities. (ImPACT Applications, Inc. is headquartered in Pittsburgh, Pennsylvania). ImPACT is a sophisticated, research-based test developed to help clinicians evaluate recovery following concussion (ImPACT Applications, 2011). The test begins with a demographic profile and health history questionnaire. This section asks the athlete to answer questions regarding height, weight, sport, position, concussion history, history of learning disabilities and other important descriptive information. The next section of the ImPACT test addresses current concussion symptoms and conditions and asks questions about the athlete's most recent concussion date, hours slept the previous night, and current medications (ImPACT Applications, 2011). The athlete completes a 22-item self-report of symptoms scale, rating current symptom severity on a 7 point Likert scale. The symptoms on this self-report scale are similar to those used on the SCAT2 test, but not exactly identical.

Next the ImPACT test moves on to 6 neurocognitive modules. Portions of these 6 modules are combined to calculate 5 composite scores (visual memory, verbal memory, visual motor speed, reaction time and total symptom score).

Module 1 is word discrimination. Twelve target words are presented twice, and then 24 words are presented. Twelve of these words are the original target words, and 12 of them are non-target words. The athlete has to identify the target words. This module evaluates attention processes and verbal recognition memory (ImPACT Applications, 2011). Module 4 is symbol matching. This module evaluates visual processing speed, learning and memory. The athlete is presented with 9 common symbols that are associated with the numbers 1-9. When these symbols are presented, the athlete clicks on the corresponding number as quickly as possible. Correct performance is reinforced with a number lighting up in green. Negative selections result in the incorrect number lighting up in red (ImPACT Applications, 2011). Module 6 is three-letter memory. This module measures working memory and visual-motor response speed. The athlete is presented with 3 consonant letters displayed on the screen. Next a distractor task is presented. A 5 x 5 grid appears with numbers from 1-25 in a random order. The athlete has to count backwards from 25 by clicking on the numbers as quickly as possible. After a period of 18 seconds, the number grid disappears and the athlete is asked to type in the 3 consonants (ImPACT Applications, 2011). The average performance on modules 1, 4 and 6 represent the verbal memory composite score (ImPACT Clinical Interpretation, 2007).

Module 2 is design memory. This module evaluates attention processes and visual recognition memory. Similar to module 1, 12 target designs are shown twice and during a third viewing, the athlete is asked to identify the target designs from the non-target designs (ImPACT Applications, 2011). The designs may appear in a rotated position. Module 3 is X's and O's. This module measures visual working memory as well as visual processing speed, and consists of a visual memory paradigm with a distractor task. The distractor task is a choice reaction time test.   The athlete clicks the left button on the mouse when a blue square appears or the right button on the mouse when a red circle is presented (ImPACT Applications, 2011). The total percent correct from modules 2 and 3 combine for the visual memory composite score.   The visual motor speed composite score is comprised of the average scores from the total number correct from module 3 and from the average counted correctly from module 6 (ImPACT Clinical Interpretation, 2007).

Module 5 is color match. This module represents a choice reaction time task and also measures impulse control and response inhibition. The athlete is required to click on a red, green or blue box as they are presented on the screen. This procedure is completed to assure that subsequent trials would not be affected by color blindness. Next a word appears on the screen in the same color ink as the word (RED) or in different colored ink than the color word. The athlete only clicks on the corresponding colored boxes if the word is spelled in the correct ink color (ImPACT Applications, 2011). The reaction time composite score is comprised of the average correct in modules 3, 4 and 5 (ImPACT Clinical Interpretation, 2007).

Self-Report Symptom Scales

Self-report symptom scales are heavily relied on in sport concussion assessment. The Consensus Statement on Concussion in Sport from the 4th International Conference on Concussion in Sport held in Zurich in November 2012 states that the post-concussion symptom scale (PCSS) on SCATs can be used as an objective tool for assessing a variety of symptoms associated with sport-related concussions (McCrory et al., 2013). The recent American Medical Society for Sports Medicine (AMSSM) position statement on concussion in sport also supports the utility of the PCSS to track the severity of symptoms over time (Harmon et al., 2013). Thus, the self-report PCSS on the SCAT2 and on ImPACT are widely used throughout sport.

Consequently, self-report of symptoms is a tool that is frequently used in concussion management by many sport medicine professionals. In one study, approximately 85% of athletic trainers (ATs) used some form of symptom assessment to evaluate concussion (Valovich McLeod & Leach, 2012). Athletes report their symptoms in the preseason, which provides a baseline TSS. A change in this TSS is used subsequently to help to determine if an athlete has suffered a concussion (in conjunction with clinical examination by a trained professional); and follow-up reports of symptoms are then used to assess whether an athlete's symptoms have resolved and when he/she can return to play. A concussion should be suspected when an athlete self-reports an increase in symptoms as compared to his/her individual baseline. This supports the importance of using an athlete's self-report of symptoms in concussion assessment.

In a meta-analysis on various assessment techniques for detecting the effects of concussion, the greatest effects immediately following an injury and at follow up were found in self-report symptoms (Valovich Mcleod 2009). The Consensus Statement on Concussion in Sport advocates a multifaceted approach to concussion assessment. In Valovich Mcleod's (2009) meta-analysis, clinicians gained the most amount of information regarding post-concussion deficits by using the SAC, a measure of postural control (the BESS) and self-report of symptoms combined. The built in self-report symptom scale in the computerized neurocognitive ImPACT test was reported to increase the sensitivity of the test anywhere from 64-83%, compared to the SAC (80%), BESS (34%) or graded symptom scale (89%) alone (Valovich McLeod, 2009). Self-report scales of post-concussion symptoms are an important feature of all concussion assessments, but they cannot be used in isolation.

In 2009, Alla et al. performed a systematic review of literature regarding self-report sport concussion symptom scales and the psychometric properties of these scales. Six core symptom scales were identified, with a broad range of symptom items. These scales had limited psychometric properties. Internal reliability measures and test-retest intervals are often reported, however these are frequently the only statistics measured. The 22 item PCSS on ImPACT has only been evaluated for the degree to which the test measures what it claims to be measuring or construct validity (Alla et al, 2009). It is also of note that the majority of symptom scales have "evolved" rather than been scientifically developed. The list of symptoms included in most of the symptom evaluations have been added to or deleted based on clinical experiences (rather than scientific method).

Many scales exist for measuring the number and severity of concussion-related symptoms. Most of these have evolved from the neuropsychology literature pertaining to head-injured populations (Valovich McLeod & Leach, 2012). A second database search by Valovich McLeod (2012), reported on 20 self-report symptom scales. Only 7 of these scales had published psychometric properties, and only 1 scale, the Concussion Symptom Inventory (CIS), was empirically driven. With this in mind, more research on athletes' self-reports on the various symptom scores, including PCSS is warranted.

Eckner et al. (2010) reviewed publications on concussion symptom scales and sideline assessment tools, and found that many of the scales have overlapping symptoms. In this review, there was a range in the number of symptoms on each scale from 9 to 34. Three of the scales were computer-based while the remainder were paper and pencil tests. The researchers even found an application for iPhone (Cognit) designed as a concussion evaluation tool for use by sports medicine providers on the sideline. Cognit guides the user through a series of questions to ask the affected athlete and saves the answers on the device. Then the answers are to be emailed to a qualified medical professional to review if the athlete has suffered a sport-related concussion (Retrieved from: https://itunes.apple.com/ca/app/cognit/id321010010?mt=8). It claims to be able to recognize when an athlete has a concussion, but there are no scientific studies to date evaluating this tool (Eckner et al., 2010). This study emphasizes the number of forms of self-report symptom scales available with varying numbers of symptoms, some of which are easily accessible by coaches, parents and athletes.

To date, there is no clear consensus regarding a specific scale for use in tracking recovery of symptoms from concussion. Randolph et al. (2009) analyzed a large set of data from existing scales to determine which symptoms were the most sensitive to concussion. The data for this study were derived from three separate projects: The Concussion Prevention Initiative, the National College Athletic Association (NCAA) Concussion Study, and the Project Sideline. From this data, the Concussion Symptom Inventory (CSI) was developed. This is the first scale that has been empirically derived for the purpose of monitoring subjective symptoms following concussion. The scale includes 12 variables: headache, nausea, balance/dizziness, fatigue, drowsiness, feeling slowed down, in a fog, difficulty concentrating, difficulty remembering, blurred vision, sensitivity to light and sensitivity to noise. Randolph (2009) argues that with the new shorter symptom scale there will be no loss in sensitivity or reliability compared to longer scales. However, since the CSI was created it has not been adopted for common use, and sport medicine professionals tend to utilize the longer post-concussion symptom scales.

An argument exists in the literature on sport concussion assessment about whether an athlete's own individual baseline PCSS has to be used for comparison at post-injury or if normative data can be used. In a recent study, Schmidt et al. (2012) compared individualized baselines with normative data in 1060 collegiate student athletes. When comparing graded symptom checklists for the ability to identify impairment in a post-concussion athlete, agreement existed between the normative and the baseline comparisons. However, Schmidt et al. (2012) still recommend completing baseline self-report symptom checklists as part of a pre-season screening process, if possible. Baseline self-reports of symptom checklists are neither time costly or expensive to administer. The standard of practice remains that where possible an individual's own baseline PCSS should continue to be used for comparison when assessing an athlete post-injury, and prior to return-to-play.

<u>Symptoms at Baseline</u>

The symptoms on a PCSS are not unique to concussion, and even healthy adults may experience these symptoms without an injury. A study was conducted assessing baseline symptoms in 1065 National College Athletic Association athletes, predominately male, ranging in age from 18-27 years. The most common self-report symptoms described during a non-concussed baseline evaluation were fatigue, headache, difficulty concentrating, drowsiness, and trouble falling asleep (Piland et al., 2010). These symptoms are also commonly reported when an athlete suffers a concussion. A baseline self-report score is not always a complete absence of symptoms, as it has been shown that even non-concussed individuals will report some symptoms (Piland et al., 2010).

Another study found that athletes who had suffered a previous concussion reported higher symptom scores on their next self-report of symptoms while being considered healthy (Hutchison et al. 2009). In this study, acute fatigue, physical illness, and orthopaedic injury also increased self-report symptom scores. Emotional responses were assessed after concussions and musculoskeletal injuries, and emotional disturbances were found after both types of injuries. When recording an athlete's baseline self-report symptoms, history of previous concussion as well as history of current musculoskeletal injuries should be noted.

Baseline values have been examined for the SCAT2 in high school athletes. Jinguji et al. (2011) administered the SCAT2 to 214 high school athletes. On average, male students reported slightly fewer baseline symptoms than females, although this was not statistically significant. The younger age group (13–15 years) exhibited a trend towards fewer baseline symptoms than the older age group (16–19 years). The most frequent baseline symptoms reported were fatigue or low energy, trouble falling asleep, difficulty concentrating, difficulty remembering and being nervous or anxious. This study reports how age and sex play a role in baseline self-report of symptoms. When an athlete reports symptoms on his/her baseline test, he/she may return to play once the post-concussion assessment returns to his/her own individual baseline – i.e. with these symptoms.

Baseline values have also been examined for the SCAT2 in varsity collision sport athletes. A study looked to differentiate those with a history of a previous concussion from those athletes who had never been concussed, and males from female athletes (Shehata et al., 2009). The study included 260 subjects, 167 with no previously reported concussion. Women had the highest mean total self-report of baseline symptoms with a score of 6.39, whereas men had the lowest with a score of 3.52. Never-concussed athletes had a mean total self-report symptom score of 3.75 and previously concussed athletes had a mean score of 5.25. The most commonly reported baseline symptoms for all groups were fatigue or low energy. Drowsiness and neck pain were ranked in the top five self-reported baseline symptoms for all athletes. The data from this study describe differences at baseline self-report in male and female athletes, and in those with a previous history of concussion.

The SCAT (original version) has been examined in 4193 male and female youth ice hockey players to determine baseline normative values. A higher proportion of previously concussed athletes reported symptoms at baseline than those who had not previously been concussed (Schneider et al., 2010). Trouble falling asleep was one of the top five most commonly reported symptoms at baseline for all subjects. Females reported a greater number of baseline symptoms than did males. The SCAT symptoms that were reported varied by age and sex, and differed from those previously reported in varsity athletes (Schneider et al., 2010). In the study by Shehata et al. (2009) female collegiate athletes consistently reported more symptoms than males, while in the Schneider et al. (2010) study the number and severity of symptoms varied across age groups and by sex. Shehata et al. (2009) stated that fatigue and low energy were the symptoms most commonly reported by collegiate athletes, while the athletes in the youth hockey study reported headache most often. This study again reinforces that those athletes who have a history of concussion may have elevated baseline symptoms, and that both age and sex affect baseline self-report of symptoms.

It cannot be assumed, in many populations, that an athlete will have no symptoms at baseline on the SCAT2. Valovich McLeod et al. (2012) conducted a study looking at representative baseline SCAT2 values in 1134 adolescent athletes, to see if sex, grade, and self-reported concussion history would affect those scores. Athletes in the 11th and 12th grades scored significantly higher than those in 9th grade. Male athletes scored significantly lower on the SCAT2 total score than female athletes. They also found that 88.7% of adolescent athletes, with a positive concussion history, reported at least one symptom at baseline, when compared with 79.5% of athletes with no concussion history. It appears that grade (age), sex and self-reported concussion history can all affect baseline SCAT2 scores.

<u>Neuropsychological Testing</u>

As previously mentioned, computerized neuropsychological testing for concussion management has become very common. A recent study of 192 high schools in the United States found that 39.9% of athletic trainers (AT) utilized computerized neuropsychological testing in the management of athletes with concussions (Meehan et al., 2012). Of those using computerized neuropsychological testing, the majority (93.0%) use ImPACT. Currently, the majority (69.9%) of schools using computerized neuropsychological testing only test athletes in certain sports. Even though ImPACT is so commonly used, it is typically only completed on athletes participating in contact or collision sports.

ImPACT is not the only computerized neuropsychological testing on the market. AXON Sports powered by CogSTATE (formerly CogSport) is an Australian based company offering online neuropsychological concussion testing and management (Retrieved from: https://www.axonsports.com/index.cfm). The Automated Neuropsychological Assessment Metrics (ANAM) was created by the U.S. Department of Defense and is a library of computerized tests for different cognitive domains (Luethcke et al., 2011). HeadMinder is another popular computer based neuropsychological testing platform, which assesses a variety of diseases and injuries (Retrieved from: http://www.headminder.com/site/home.html). All of the computerized neuropsychological tests assess a variety of cognitive domains, much like ImPACT.

According to the National Conference of State Legislatures, from 2009 to 2013, 50 states have passed laws to address traumatic brain injury (Retrieved from: http://www.ncsl.org/research/military-and-veterans-affairs/traumatic-brain-injury-legislation.aspx). These laws include using neuropsychological testing at baseline and return to play. In Canada, the province of Ontario has introduced Bill 39, an amendment to their Education Act: under Pupil Health a section titled "Concussions" has been added. It states that a student with a suspected concussion will be removed from physical education classes and intramural activities (Retrieved from: http://www.ontla.on.ca/web/bills/bills_detail.do?locale=en&Intranet=&BillID=2584).

In computerized neuropsychological testing, much like in self-report concussion symptoms, there is a debate on whether an athlete should have his/her own individualized baseline or whether an injured athlete can be compared to normative data. Grindel et al. (2001) point out that even though there is no study showing that once an athlete's neuropsychological testing has returned to baseline, an athlete is safe to return to play; measuring an athlete against his/her own baseline is still essential to ensure a "true" return to baseline. It was found that athletes with a history of multiple concussions performed worse at baseline, despite the remote occurrence of their last concussion. Individuals with poor performance at baseline were more likely to have been concussed. Grindel et al. (2001) stated that it is not possible to compare post-concussive baseline tests with the baselines of non-concussed individuals. Once again, the history of a previous concussion may affect baseline concussion neuropsychological scores.

In another comparison between individualized baselines and normative data, Schmidt et al. (2012) found discrepancies between reaction time and mathematical processing tests. This study used the computerized neurocognitive test Automated Neuropsychological Assessment Metrics (ANAM), postural control assessment (Sensory Organization Test) and a 15-item graded symptom checklist at baseline and again following injury. In comparison to an athlete's own baseline, 2.6 times more impairments were found for the simple reaction time test. Using a normative comparison method, 7.6 times more impairments were found for the mathematic processing tests. Age-matched normative values have been created for neuropsychological testing with the argument that these values can be used in lieu of individualized baseline measures. This study shows that there may be some discrepancies, so it is important to be aware of this potential limitation. Much the same as self-report of symptoms, neuropsychological testing is affected by age, sex, and previous concussion history. There is a need to assess if athletes report symptoms differently on the paper and pencil SCAT2 versus the computerized ImPACT.

Many studies have demonstrated that cognitive deficits remain, even when post-concussion symptoms have resolved. McCrea at al. (2005) found that a significant number of their 94 subjects reported being symptom free by day 2 post-injury, but continued to be classified as impaired on the basis of cognitive testing. Broglio et al. (2007) reported similar findings with 38% of their 21 asymptomatic concussed subjects demonstrating impairments on at least one variable on ImPACT testing. In comparison of another group of 44 concussed collegiate athletes with no subjective symptoms and a control group of 70 non-concussed collegiate athletes, the concussed group demonstrated poorer performance on four ImPACT composite scores (Fazio et al., 2007). Therefore, it is important to use a variety of concussion assessment instruments and not rely on self-report of symptoms alone to make return to play decisions.

These studies indicate the importance of continuing to do serial examinations on athletes who have suffered a sport-related concussion. Despite the fact that they are no longer reporting post-concussion symptoms, they may still be experiencing cognitive delays. Covassin et al. (2009) surveyed 399 athletic trainers in the United States and asked if they would return an athlete to play if they were symptom free but scored below baseline values on ImPACT. The responses were not as predicted: 86.5% responded no, 9.8% responded yes, and 3.8% indicated that it depended on the importance of the competition. These results indicate inconsistent use of concussion protocols by sport medicine professionals.

Many computerized neuropsychological testing platforms have been assessed for psychometric properties. ImPACT is reported to have a sensitivity of 81.9% and a specificity of 89.4% for the diagnosis of concussion (Lau et al., 2011). Lau et al. (2011) noted that the total score on the PCSS was greater in the protracted recovery (≥14 days) group within 2-3 days of injury and that it had a predictive value for protracted recovery. Concussion symptoms were divided into four clusters: somatic, cognitive, emotional and sleep disturbances (Appendix 2.0). Discriminate function analysis was used to determine that athletes who reported more symptoms in the somatic and cognitive clusters required longer recovery times (Lau et al., 2011). A reliable change index (RCI) was used to conclude that when neuropsychological testing is used in conjunction with self-report symptoms, a net increase of 19% in sensitivity was found (Van Kampen et al., 2006). Neuropsychological testing can improve concussion diagnosis and may also play a role post-injury in predicting length of recovery.

In a subsequent study of 108 male high school football athletes, Lau et al. (2012) attempted to determine cut-off scores in computerized neuropsychological testing and symptom clusters that could predict protracted recovery from sport-related concussion. These researchers again used ImPACT and the PCSS contained within it for self-report of symptoms. It was found that 76% of non-injured athletes had a total score of 6 or less on the PCSS (Lau et al., 2012). These researchers suggest 75%, 80% and 85% sensitivity cut-off values for symptom reports within a median of 2 days after injury with the ability to accurately identify protracted recovery (≥14 days) (Lau et al., 2012). The somatic symptom cluster and cognitive symptom cluster both provided statistically significant results for discriminating between a short or protracted recovery from concussion. It is common for headaches (member of the migraine cluster) and fogginess (member of the cognitive cluster) to persist in patients during protracted recovery (Lau et al., 2012). Both of these studies (Lau et al., 2011, 2012) found a prediction for protracted recovery using ImPACT on athletes in post-injury situations.

In a complex study looking at the test-retest reliability of ImPACT on healthy subjects (Resch et al., 2013), many deficits were found in the absence of a sport-related concussion. Group 1 completed a baseline test and then were reassessed on day 7 and day 14. Group 2 completed a baseline test and then were reassessed on day 45 and day 50. In group 1, 37% of 46 participants were classified on 1 or more composite scores as impaired at the second time point. At the third time point, 46% of the group 1 participants were classified as having a change from baseline. In group 2, 22% of 45 participants achieved a different score on 1 or more composite scores at the second time point. At the third time point, 29% of participants in group 2 were considered different from baseline

(Resch et al., 2013). The use of ImPACT testing alone misclassified this healthy non-concussed college-aged adult sample at different time points from baseline.

The ImPACT test battery was designed to reduce practice effects through randomization of stimuli presentation. This is an essential design feature, because the test is intended to be used repeatedly, over short intervals (ImPACT Applications, 2011). Schantz et al. (2006) explored the diagnostic utility of the ImPACT composite scores and the post-concussion symptom inventory in a sample of 72 concussed high school athletes. In their study, athletes who had suffered a concussion were age-matched with athletes who had not suffered a concussion in a discriminate function analysis. ImPACT had a high specificity rate, correctly identifying an athlete who had suffered a concussion from an athlete who had not suffered a concussion 85.5% of the time from the visual memory, processing speed, impulse control and post-concussion symptom checklist composite scores. ImPACT appears to be helpful in distinguishing between concussed and non-concussed athletes at the time of injury, but the test-retest reliability is less dependable.

The amount of activity that athletes engage in post-concussion can affect their self-report of symptoms. Majerske at al. (2008) used an activity intensity scale to record how much activity 95 athletes were doing at school, at home and with their sports team. Athletes performing the best on neuropsychological tests and reporting the lowest symptom scores engaged in intermediate levels of activity after concussion. Given that both mental and physical exertion can change the metabolic activity of the brain, cognitive activities could also potentially worsen the metabolic mismatch after concussion (Majerske at al., 2008). This is an interesting point, which needs to be considered when scheduling computerized neuropsychological testing. The issue of the student-athlete is also brought to the forefront. Symptom exacerbation could be the result of school-related cognitive activities.

Researchers have reported both males and females and those who have a history of concussion show differences at baseline and at post-concussion on computerized neuropsychological testing. Covassin et al. (2010) examined differences among 100 male and 88 female athletes with a history of multiple concussions. Athletes were administered the baseline version of ImPACT. Females with a history of two concussions performed better on the verbal memory composite score than males (p=0.001) and females with a history of three or more concussions performed better than males (p=0.012). Females also performed better than males with a history of three or more concussions (p=0.021) on visual memory. There was a significant difference between sexes on both motor processing speed and reaction time composite scores. Males performed worse than females on both motor processing speed (p=0.029) and reaction time (p=0.04) (Covassin et al., 2010). With computerized neuropsychological testing, as with SCAT2, the sex of the athlete and history of a previous concussion will affect baseline ImPACT composite scores.

A different study looking at 201 collegiate athletes also examined self-report of symptoms in athletes with no history of sport-related concussion, as compared with a group of athletes who had suffered a previous concussion.

Participants completed a paper and pencil concussion history questionnaire. All participants were asked to respond yes or no to whether or not they had experienced any of the signs and symptoms listed following head impact in a game or practice in the previous year. Within the non-concussed group, athletes reported experiencing concussion signs and symptoms never (41%), rarely (41%), sometimes (13%) and frequently (5%) following head impact (Mansell et al., 2010). Athletes with a history of at least one prior diagnosed concussion were more likely to report signs and symptoms following a head impact. This suggests two possible explanations, both of which might be correct. First of all, a previous sport-related concussion may increase an athlete's susceptibility to injury. Secondly, an athlete who has previously suffered a concussion may be more aware of post-concussion symptoms that may result from an impact to the head.

Collegiate athletes who have been previously concussed have been shown to be more likely to sustain additional concussions with head impact or acceleration events. Guskiewicz et al. (2003) in a study of 184 college football players found that athletes who had suffered 3 or more concussions were 3 times more likely to sustain another concussion, compared to football players who had no previous concussion history. Other authors note that the athletes without a previously diagnosed concussion may have been athletes who were uneducated or who hesitate to report signs and symptoms following a head impact (Mansell et al., 2010). Faulty reporting may influence both previously concussed and non-concussed athletes' self-report of symptoms.

It has been questioned whether or not computerized neuropsychological testing modifies the risks involved with managing sport-related concussions. Randolph (2011) identified four risks that could be associated with sport-related concussions: death or permanent neurological injury, same-season repeat concussion, delayed/atypical recovery, and late-life effects of multiple concussions or repetitive head trauma. These risks are all quite rare. In reviewing 10 seasons of American football at all levels of play (ending in 2006), there were a total of 50 cases of permanent disability and 38 deaths from cerebral injuries (Randolph, 2011). One of the fears with same-season repeat concussion is the occurrence of a condition known as second impact syndrome (SIS). Second impact syndrome results from a second incident of head trauma before the first injury has resolved, and it results in diffuse cerebral swelling. Rare events such as death and permanent neurological injury cannot be prevented with baseline neuropsychological testing.

The research presented above demonstrates that neuropsychological testing may be able to help identify those athletes who will have a protracted recovery. Late-life effects of multiple head trauma can sometimes be the result of neuropathological changes (e.g. chronic traumatic encephalopathy), but these have mainly been documented in professional football players and boxers. It is not thought that this is a common complication for the majority of athletes who sustain a sport-related concussion (Randolph, 2011). Baseline computerized neuropsychological testing is another tool that sport medicine practitioners can use to determine if an athlete is ready to return to play, but it must be used along with clinical assessment and resolution of symptoms described on self-report.

Abnormal test scores are frequently found in healthy adults who perform neuropsychological testing. "Abnormality" has been defined as a score more than one standard deviation below the mean (Binder et al., 2009). These abnormalities could be the result of: measurement error, longstanding weaknesses in certain areas, fluctuations in motivation and effort, psychological interference, and other situational factors such as inattentiveness, fatigue, or minor illness. Post-concussion type symptoms are also found in healthy adults. Chan (2001) looked at 85 participants without head injury, neurological or psychological disease. The most commonly reported symptoms were longer time to think, poor concentration and forgetfulness, fatigue easily, sleep disturbance, and irritability. All of these symptoms can also be self-reported by someone after suffering a sport-related concussion. Reasons for having these symptoms may include: academic or work affairs and emotional distress associated with environmental changes (Chan, 2001). The use of self-report symptoms alone is not sufficient to determine whether or not an athlete is suffering from post-concussion syndrome.

The use of neuropsychological baseline testing has been widely implemented in schools, universities and with professional sport teams. It is common practice for this testing to occur in a group setting to save time. Scolaro Moser et al. (2011) found that athletes who performed neuropsychological baseline testing in a group setting scored significantly lower on verbal memory, visual memory, motor processing speed, and reaction time, but not on symptom scores. Comparing a post-concussion neuropsychological test, which was obtained in an individual test setting, to a baseline neuropsychological test that was obtained in a group setting may be problematic (Scolaro Moser et al., 2011). Testing environment can influence neuropsychological testing performance.

Additional Factors Affecting Self-Report Symptoms

Many factors can affect self-report of symptoms and neuropsychological testing, such as hydration level for example. Patel et al. (2007) divided 24 healthy athletes into two groups: dehydrated and euhydrated. The total number of symptoms reported for the dehydration condition was significantly higher than that observed for the euhydrated condition. The four most commonly reported symptoms were feeling slowed down, fatigue/drowsiness, difficulty concentrating and balance problems. Weber et al. (2013) examined 32 NCAA wrestlers and their weight-cutting tactics using preseason baseline concussion testing during a pre-practice and post-practice session. The number of Graded Symptom Checklist (GSC) symptoms reported was higher for the pre-practice and post-practice measures as compared to baseline when athletes were euhydrated. Healthy young adults are at risk of a decrease in their cognitive performance when hydration is not adequate. Adan (2012) found that being dehydrated by just 2% impairs performance in tasks that require attention, psychomotor, and immediate memory skills. When athletes are experiencing dehydration, they report more post-concussion symptoms. A thorough on-field assessment is needed to rule out the presence of dehydration or a heat-related illness. The above studies demonstrate that when athletes are dehydrated they report a greater number of post-concussion symptoms.

Researchers at the University of Alberta examined how fitness level and fatigue might impact a varsity athlete`s self-report of symptoms. After doing baseline testing using the SCAT2, 125 subjects performed the Leger (Beep) Test in the form of a 20m-shuttle run. Approximately 10 minutes after completion of the run, athletes filled out a second self-report of symptoms evaluation. Athletes returned 24 hours later and completed the symptom scale for a third time. Results showed that individuals in the high fitness group reported a significantly lower number of symptoms compared to the lower fitness groups (Mrazik et al., 2013). Fitness groups were determined by using the criterion established by the American College of Sports Medicine. Those subjects with VO2max scores above the 60^{th} percentile were assigned to the high-fitness group, whereas those below the 60^{th} percentile were assigned to the low-fitness group. Scores increased immediately post exertion, while on follow-up testing 24 hours later, the majority of test results had returned to baseline. The current return to play protocol following concussion requires that an athlete remain symptom free for two days before beginning light aerobic activity. Fatigue or low energy, which may be a product of fitness level, is a symptom listed on the SCAT2 and may be reported by an athlete following an activity with a high level of exertion.

The time of day can affect symptom severity in athletes who have suffered from a sport-related concussion. A new research method called ecological momentary assessment (EMA) was used to capture the moment-to-moment fluctuations in symptom expression that result from changing environmental demands (Lewandowski et al., 2009). In this pilot study, 6 student athletes were given a Palm Pilot 100 where they could provide contextual information (classroom, lunch, home) and record items on a Symptom Severity Scale (SSS). All students were instructed to record data on the Palm Pilot for five consecutive days (Monday–Friday) at five time intervals: 9–10 a.m., 11 a.m.–12 p.m., 2–3 p.m., 5–6 p.m., and 8–9 p.m. In general, symptoms tended to get worse as the day wore on, with increased severity by the end of the school day (2–3 p.m.). Students with concussion tend to maintain a level of symptom severity into the evening (8 p.m.), whereas controls tend to be relatively symptom-free once out of school (Lewandowski et al., 2009). This article introduces the idea of taking self-report of symptoms at the same time each day so as not to conflict with environmental stresses and circadian rhythms.

The female menstrual cycle can affect self-report of post-concussion symptoms. Mihalik et al., (2009) were concerned with the effect of the menstrual cycle and examined 36 healthy female college athletes. Female athletes who had a healthy menstrual cycle (eumenorrheic females who tracked their menstrual cycle on a daily basis) reported a higher number of symptoms and had an increased symptom severity scored as compared to female athletes taking oral contraceptive pills (OCP). The authors suggest that eumenorrheic females exhibit an increase in mood-related symptoms and depression scores compared to OCP users. This may be related to changes in serotonin levels during the luteal phase for the females not taking hormones. Nevertheless, self-report of post-concussion symptoms remained constant throughout the menstrual cycle. Based on the results of this study, menstrual cycle phase (either follicular or luteal phase) does not need to be accounted for in pre and post-injury reporting (Mihalik et al., 2009). The symptoms experienced by eumenorrheic females are similar to post-concussion symptoms and this could be an explanation for the increased mean TSS for female athletes. When completing a preseason medical history with female athletes, sport medicine professionals should pay attention to oral contraception use and document irregular menstrual cycles (Mihalik et al., 2009).

Musculoskeletal injuries can produce emotional symptoms in athletes. Negative emotions such as shock, depression, anger, frustration, anxiety, fear, and uncertainty can emerge after a musculoskeletal injury (Hutchison et al., 2009). Athletes tend to self-report more fatigue and decreased vigor following a sport-related concussion. These findings suggest that the emotional reaction after concussion is different from that of musculoskeletal injury. However, clinicians need to be aware that these emotional symptoms are present with both injury types.

Predictive Value of Concussion Tests

While many studies on sport-related concussions have examined the presence of and differences in self-report symptoms at baseline, one study examined these symptoms post-injury. Frommer et al. (2011) investigated how sex of the athlete might play a role in the type of signs and symptoms seen post-concussion and in the recovery time. This study was conducted through an internet-based injury surveillance system, the high school sport-related injury surveillance system, RIO (Reporting Information Online, Columbus, OH), in the United States. It included observations based on 812 athletes from 100 different schools. There was a difference in the type of symptoms reported for each sex. Males reported amnesia and confusion/ disorientation more often than did females. Females reported drowsiness and sensitivity to noise more often than did males. The average return to play time period for males was between 7 and 9 days. The average return to play time period for females was between 3 to 6 days. The athletes' sex should be taken into consideration when reviewing a self-report symptom checklist administered following a sport-related concussion.

Researchers have also been interested in the presence of on-field signs/symptoms and their predictive value for recovery from concussion. In 2001, Cantu reported that the duration of post-traumatic amnesia (PTA) was the best indicator of traumatic brain injury severity. He stated that both retrograde and anterograde amnesia should be assessed at time of injury in order to grade concussion severity. Since then, the Prague 2004 consensus statement on Concussion in Sport has recommended that the nature, burden, and duration of post-concussive symptoms may be more important than the presence or duration of amnesia alone (McCrory et al., 2005). For several decades, loss of consciousness (LOC) was also used as an indicator for concussion. In similar findings as the amnesia research, LOC was not found to be necessary in defining concussion severity (McCrory et al., 2005). Neither PTA nor LOC are considered to be predictors of concussion severity anymore.

Researchers in sport concussion continue to examine symptoms immediately post-injury for predictive value. In 2003, Collins et al. showed that, in a group of 78 concussed athletes, those with a poor presentation at two days post-injury were four times more likely to have exhibited PTA. Asplund et al. (2004) found that of 101 concussed athletes, those who reported having headache symptoms for more than three hours, difficulty concentrating for more than 3 hours, retrograde amnesia, or loss of consciousness had a more severe injury or prolonged recovery. Athletes who had headaches lasting less than three hours were able to return to play within seven days as compared to only 58% with headaches lasting longer than 3 hours (Asplund et al. 2004). Specific symptoms reported in concussed athletes post-injury may be useful to predict length of recovery.

The simple versus complex grading system was examined by Iverson in 2007 to determine if the category could be predicted at 48 hours post-concussion, and retrospectively which athletes would fall under which diagnosis. A diagnosis of a simple concussion was given after symptoms had resolved within 7-10 days and a diagnosis of a complex concussion was assigned to those athletes who suffered persistent symptoms. Athletes with simple concussion diagnoses had significantly better neuropsychological test scores. Athletes with complex concussions had significantly greater total PCSS (Iverson, 2007). This grading system for concussion is no longer used, following the most recent two (2008, 2012) concussion consensus conferences (McCrory et al., 2005 and Aubry et al., 2001), as it was not very clinically useful, being mainly a retrospective diagnosis.

Two studies were conducted with high school athletes to determine if neurocognitive tests and self-report of symptoms could predict prolonged recovery post-injury. In 2009, Lau et al. found that visual memory and processing speed composite scores from ImPACT were significantly worse in 61 athletes with complex concussions compared with 47 athletes with simple concussions. They also identified which symptom clusters were more common in those athletes with complex concussions at post-injury. Those athletes with somatic, sleep and cognitive symptoms recovered more slowly. As mentioned already, by 2011, the simple and complex diagnosis terms had been abandoned, and now researchers were interested in protracted recovery (>21 days) and rapid recovery (<7 days). In a follow-up study of 107 male high school football players the mean recovery times in days for the rapid and protracted groups were 4.31 and 29.61. (Lau et al., 2011) Dizziness at the time of injury was associated with a 6.34 odds ratio for a protracted recovery. Neuropsychological testing along with self-report of symptoms at the time of injury may predict protracted recovery.

Academic, occupational and athletic accommodations could potentially be planned if clinicians are able to anticipate which athletes might be at risk for a protracted recovery. Meehan III et al., (2013) divided 182 subjects who had suffered a sport-related concussion into two groups: those whose symptoms had resolved within 28 days and those whose symptoms persisted beyond 28 days. They found that PCSS total score was associated with an increased odds ratio for a prolonged recovery. Study participants with a mean PCSS total score of 33.3 were more likely to have symptoms for greater than 28 days. Participants with a mean PCSS of 16.6 were more likely to have symptoms resolve within 28 days. The odds of prolonged symptom duration increased with increasing PCSS score. The adjusted Odds Ratio (aOR) for PCSS was 1.039 (which represents a difference in odds per point increase on the PCSS) (Meehan III et al., 2013). Self-report of a greater TSS at time of injury was shown in this study to predict protracted recovery.

A battery of concussion tests is recommended for a comprehensive assessment. Barlow et al. (2011) looked at the possible predictive value of the PCSS, BESS and the five subscales of ImPACT for the presence of post-concussion syndrome (PCS) at a baseline and at a post-injury assessment. They found that no single test had any predictive value for PCS at time of injury for this group of 106 middle school and high school aged athletes. There was an inverse relationship between PCSS and PCS. Athletes who had a lower baseline score or self-reported less symptoms, more commonly had a diagnosis of PCS. This is a counterintuitive finding, and the reason could potentially be the lack of universal definition for PCS.

There is a large body of research from hospital emergency departments (ED) on patients who present with a mild traumatic brain injury (mTBI). Of the patients who present with 3 symptoms or more early in the ED, 50% have not recovered within 6 months. The presence of headache, dizziness or nausea in the ED, after an mTBI, is strongly associated with the severity of post-concussion syndrome after six months (de Kruijk et al., 2002). Another study of 507 patients found that baseline mental health and physical health status were predictive of mTBI persistent symptoms (McLean et al. 2009). Jacobs et al. (2009) found CT abnormalities in only 20.7% of their 2784 study subjects presenting in an ED. Age, extracranial injuries, and day-of-injury alcohol intoxication proved to be stronger outcome predictors for prolonged recovery six months following the mTBI (Jacobs et al., 2009). Again, the studies in EDs have been done in an already injured population and cannot predict prior to the injury who may receive a mTBI.

Pre-injury resiliency and mood have found to be potentially protective against PCS (McCauley et al., 2013). Researchers used the Acute Stress Disorder Scale and PTSD-Checklist-Civilian forms to measure anxiety and mood. Their results showed that pre-injury depressed mood and resilience are significant contributors to the severity of post-injury symptoms with both their 46 mTBIs subjects and their 29 orthopedic injured subjects (McCauley et al., 2013). It is possible that an athlete's mood may affect his/her post-injury report of symptoms, but this may be difficult and not practical to measure at baseline.

In a PUBMED online database search (15/9/13) of articles including the words "concussion" and "predictive" or "risk factors", no articles were found that examined baseline concussion test values and whether they could be used to predict either future concussion or prolonged recovery. Many studies looked at biomechanical parameters in helmeted athletes wearing sensors and quantified linear and rotational head accelerations. This examination of head movement was after an athlete was diagnosed with a sport-related concussion. Beckwith et al. (2013) found that athletes who were diagnosed immediately with a concussion had higher kinematic measures of impact versus athletes who had a delayed diagnosis who had an increased number of impacts. No studies have directly looked at identifying potential risk factors for concussion from baseline concussion testing values.

Another potential risk factor that researchers have considered is serum biomarkers such as protein S-100B and creatine kinase as possible indicators of concussion. Again these have been examined only in athletes after they have been diagnosed with a sport-related concussion. Emergency room (ER) physicians have compiled post-injury assessments of mTBIs in an attempt to predict post-concussion syndrome. Some of these assessments include computed tomography (CT) scans or the Glasgow Coma Scale (GCS). At this time it is not possible to pre-screen athletes with blood tests or neuroimaging for possible risks for sustaining a concussion.

Recently, baseline SCAT2 values have been examined for potential risk factors for subsequent concussion in elite youth ice hockey players. Blake et al. (2013) examined 764 male and female athletes from 12-17 years old. They found that elite ice hockey players 15-17 years old with a previous history of concussion were at a greater risk for a future concussion. Higher baseline TSS and SCAT2 total scores in the lowest 25^{th} percentile were also predictive of concussion (Blake et al., 2013). These results have only been reported in an abstract form but it does reinforce the need to further investigate how to identify increased risk of concussion from baseline assessments.

Multiple studies report that self-reported concussion history does not influence future performance on neuropsychological tests. Broglio et al. (2006) examined results of 235 HeadMinder baseline assessments and 264 ImPACT baseline assessments in a population of 514 collegiate athletes. Their data suggested that baseline performance on these two concussion assessments did not differ between subjects reporting up to three previous concussions and those reporting no previous concussions. They also examined baseline concussion assessments and history of concussion, and found no predictive value for performance at baseline (Broglio et al., 2006). This study claims that athletes with a previous history of concussion will not score significantly different than athletes without a history of concussion. This is contrary to other studies.

Another group of studies examining previous history of concussion and baseline neuropsychological performance were conducted by Bruce & Echemendia (2009) on 858 male collegiate athletes. Study 1 examined the association of self-reported concussion history and performance on ImPACT, Study 2 examined the association of self-reported concussion history and traditional neuropsychological tests, and Study 3 examined association of self-reported concussion history and both computerized ImPACT and traditional neuropsychological tests. No significant association was found between self-reported concussion history and performance on any of these tests. The information from this study is encouraging because it appears that there are no lasting neurocognitive deficits in those athletes self-reporting previous concussions. Further research still needs to be done to determine who may be at risk for long-term deficits following concussion and if it is possible to determine this from neuropsychological testing at baseline.

In 2010, Belanger et al. conducted a meta-analysis on the possible effects of a history of multiple concussions on neuropsychological testing performance. It was found that both executive functions and delayed memory were associated with multiple self-reported MTBIs. However the effect sizes in their study were considered small and their clinical significance was unclear. Some studies have suggested a dose response relationship after long participation in boxing or soccer on neuropsychological performance. The extent to which a "threshold effect" exists has yet to be determined. It is likely that such a threshold is person specific and difficult to determine (Belanger et al., 2010).

It does appear that on-field symptoms can indicate those athletes who will take longer to recover. Physicians in EDs have looked at patients presenting at time of injury and found a number of factors that can predict prolonged recovery. These studies still do not predict which athletes at baseline may be more susceptible to suffering a sport-related concussion or having a protracted recovery. The majority of research does not seem to demonstrate long-term cognitive deficits for athletes with a previous history of concussion. The current study may contribute important information using computerized neurocognitive testing to determine which athletes may be at risk for a future concussion.

Chapter 3

Methods and Procedures

The participants in this study were varsity athletes in contact and collision sports at the University of Alberta. Data was collected for three consecutive athletic seasons – 2010/11, 2011/12 and 2012/13. The teams included in the study were men's and women's ice hockey, men's football, women's rugby and men's and women's soccer. Men's and women's basketball and men's and women's wrestling were added in the 2012/13 season. Procedures regarding the collection and administration of the study were approved by the University of Alberta's Research Ethics Board. Written informed consent was obtained from all participants before enrolment in the study.

Baseline testing with the original paper and pencil version of SCAT began in 2005 at the University of Alberta and continues today. Baseline testing with the computerized ImPACT only began in 2010. In the 2010/2011 season, baseline concussion data was collected from 119 male athletes and 78 female athletes. In the 2011/2012 season, baseline data was collected from 45 male athletes and 23 female athletes. In the 2012/2103 season baseline data was collected from the original six teams, as well as for the basketball and wrestling teams. This included 60 male athletes and 43 female athletes. The athletes in 2010/2011 ranged in age from 17 to 25 years with a mean age of 20 years (SD = 2). The athletes in 2011/2012 and 2012/2013 had similar demographics and ranged in age from 16 to 25 with a mean age of 20 years (SD +2).

All the varsity teams with student therapists were required to complete pre-season baseline testing with a paper and pencil version of the SCAT2. The baseline testing was conducted by either an athletic therapist or a student therapist assigned to the team. At the start of each new athletic season, the head athletic therapist reviewed with the varsity therapy staff how to complete the SCAT2. All injuries were documented by the team therapist and emailed to the head athletic therapist weekly and injury report forms were completed. If an athlete suffered a concussion during the athletic season, he/she immediately completed a post-injury SCAT2 with the team therapist. The concussed athletes were referred to a sport medicine physician at the Glen Sather Sport Medicine Clinic (GSSMC). The physicians once again had the athletes complete a post-injury SCAT2, and continued to see them in follow-up examinations until they were cleared to return to play. Chart notes, and the SCAT2 forms completed by the physicians were kept in the secure electronic medical record (EMR) system. All documents were kept on file in the Central Care Therapy Room.

Contact and collision sport varsity athletes at the University of Alberta also received pre-season baseline computerized neurocognitive testing through ImPACT. ImPACT pre-season testing occurred in 2010/2011 for all athletes with the six teams of contact/collision sports; in 2011/2012 for first year athletes and those who suffered a concussion in the previous season; and in 2012/13 for first year athletes on the original six teams, plus all athletes on the basketball and wrestling teams. The head athletic therapist scheduled days and times for varsity athletes to meet in a computer lab and take the test simultaneously. Data were stored online from the baseline ImPACT tests.

As each ImPACT test was retrieved for data entry, a clinical report was generated with norms. The norms were created from a sample of 410 university men and 97 university women. The normative data is based on a natural distribution of scores from this sample of university students (ImPACT Applications, 2011). Exact percentile ranks were assigned to the natural distribution and literal averages labeled. An athlete, who scored outside these norms, having a statistically lower score, would be considered concussed. It is important to note that ImPACT has internal checks for invalid tests. An invalid test would have composite scores, which would be 2 standard deviations below the normative data collected by ImPACT in 2011. Some common reasons for invalid baseline tests are failing to read the directions properly, "horseplay" when athletes are not properly supervised, left-right confusion on the keyboard or "sand-bagging" when an athlete purposely tries for a poor performance (ImPACT Interpretation Manual, 2007). If an invalid test occurred at baseline, a neuropsychologist reading the clinical reports would discuss this with the athlete and the test would be re-administered if deemed necessary. However, none of the baseline tests from this study were found to be invalid.

An ImPACT clinical report provides the following composite scores: memory composite (verbal), memory composite (visual), visual motor speed composite, reaction time composite, impulse control composite and total symptom score (TSS). The clinical report also lists individual scores for 22 post-concussion symptoms. These symptoms can be grouped into four symptom clusters: somatic, sleep, cognitive and neuropsychiatric (Lau et al., 2011). All of the composite scores, except impulse control composite, were used as variables to identify risk factors at baseline for a sport-related concussion. Impulse control was not used as a variable because it is a built in check for validity and provides a measure of error on each test (ImPACT Interpretation Manual, 2007). For the verbal and visual memory composites, the lowest 10th percentile would be a smaller value. For the visual motor speed, reaction time and TSS, the lowest 10th percentile would be a larger value. Normative data has been published for university men and women providing "impaired" (10th percentile) to "very superior" (100th percentile) scores for each composite score on ImPACT (ImPACT Applications, 2011).

A preseason concussion questionnaire was constructed from a variety of resources including pertinent questions on issues considered to be concussion modifiers (Lebrun & Mrazik, 2010; Appendix 1.0). The questionnaire was also completed by first year varsity athletes while they were performing ImPACT baseline testing. The questionnaire required each athlete's age, sex, height, weight and approximate grade point average (GPA). As well, there were sport specific questions including position played and amount of physical contact the athlete engaged in. The questionnaire also addressed previous concussion/head injury information and asked athletes about learning disabilities or mental health conditions. The questionnaire concluded with a series of questions asking about each athlete's level of physical conditioning.

Data Analyses

This study used the Statistical Package for Social Sciences (SPSS) version 18 (SPSS Inc. Chicago, Illinois), and statistical significance for all analyses was set at $P < 0.05$. In total, 349 complete sets of observations were collected, including 218 from males (62.5%) and 131 from females (37.5%) on the paper and pencil version of SCAT2 and the computerised version of ImPACT.

Each symptom was evaluated separately. Between the symptom scales on the two test instruments, 18 of the symptoms “matched”, or were similar enough in wording that the study investigator considered them to be asking the same question. Analyses began with assessment of the descriptive statistics of the self-report symptoms as stated by male and female athletes on each test. A mean symptom score was calculated for each test symptom for both male and female athletes, and then these were later combined for a total score for each symptom. Multiple analysis of variance (MANOVA) was used to determine if there was a statistically significant difference between the two tests using a Hotelling’s trace. A MANOVA was also conducted on the 18 “matched” self-report symptoms.

Pearson Chi Square, Chi Square cross tabulation as well as multivariate logistic regression models were used to compare those athletes who scored above and at or below the 10^{th} percentiles on ImPACT composite scores and post-concussion symptom clusters. Odds ratios and 95% confidence intervals were calculated from the corresponding regression coefficients. An increased odds ratio in a variable would indicate an increased risk for future concussion. The 10^{th}

percentile was chosen as a cut-off score for this study because it is a commonly used cut-off for consideration of impairment (Donders & Levitt, 2012). These cut-off scores also coincided with the “below average” range of scores from the ImPACT published normative data (ImPACT Applications, 2011). The varsity injury report forms from the 2010-2011, 2011-2012 and 2012-2013 varsity athletic seasons were analyzed to determine if there were any relationships between composite scores and the risk of concussion.

The responses on the preseason concussion questionnaires were compared between concussed and non-concussed athletes in the 2010/2011, 2011/2012 and 2012/2013 athletic seasons. Multivariate logistic regression models were again used to assess whether the above variables were significant for an increased odds ratio. An increased odds ratio in a variable would again indicate an increased risk for future concussion.

Chapter 4

Results

After collecting baseline concussion data for three varsity athletic seasons, 2010-2011, 2011-2012 and 2012-2013, statistical analyses were performed on 349 observations, which included 218 males (62.5%) and 131 females (37.5%). The mean age overall was 20 (SD = 2), with a range from 16-28 years of age. Baseline data was initially collected on 356 athletes but those without full records on SCAT2 or ImPACT were excluded from the analyses of self-report of post-concussion symptoms.

In a comparison between SCAT2 and ImPACT post-concussion symptom scales, it was determined that 18 of these 22 self-report symptoms were "matched" with similar phrasing, as well as the total symptom score (TSS). These symptoms included: headache, nausea, balance problems, dizziness, fatigue, trouble falling asleep, drowsiness, sensitivity to light, sensitivity to noise, irritability, sadness, nervousness, feeling more emotional, feeling slowed down, feeling mentally foggy, difficulty concentrating, difficulty remembering, visual problems.

The combined male and female mean scores from the ImPACT tests were higher for 13 of these symptoms and were higher for the TSS, indicating that athletes reported more symptoms or more severe symptoms on ImPACT versus SCAT2. Females had higher mean self-report TSS on both baseline tests: with a mean score of 7 on ImPACT as compared with 5 for males, and 4 on SCAT2 as compared with 3 for males. Since these means were not statistically significant the results were combined for further analyses. A clinically significant difference would be a change of 2 or more points on a post-concussion symptom scale (Barlow et al., 2010).

Overall, the self-report of post-concussion symptoms on ImPACT was significantly different than on SCAT2 (Hotelling's trace $p<.000$). There were significant differences between mean values for SCAT2 and ImPACT on 10 of the self-reported symptoms including: headache (p=.005), nausea (p=.009), fatigue (p<.000), trouble falling asleep (p<.000), drowsiness (p<.000), irritability (p<.000), sadness (p<.000), nervousness (p =.003), feeling more emotional (p<.000), and feeling mentally foggy (p=.001). For 8 of these symptoms the means were higher on ImPACT than SCAT2. For 2 of these symptoms the means were higher on SCAT2 than ImPACT. In general, both male and female athletes reported more symptoms or more severe symptoms on the self-report symptom score of the ImPACT test, as compared with the SCAT2 test (Figure 1.0).

During the 2010-2011 varsity athletic season, 18 concussions were recorded including 11 in men's football (2 of these were from athletes who suffered 2 concussions in the same season), 2 in men's ice hockey, and 5 in women's rugby. During the 2011-2012 season, 31 concussions were recorded including 14 in men's football (1 of these was from an athlete who suffered 2 concussions in the same season), 4 in men's ice hockey (1 from an athlete who also suffered a previous concussion in the 2010/2011 varsity season), 2 in men's soccer, 7 in women's ice hockey and 4 in women's rugby (1 from an athlete who also suffered a previous concussion in the 2010/2011 varsity season). During the 2012-2013 season, 27 concussions were recorded. This included 14 in men's football (3 of these were from athletes who also suffered a previous concussion in the 2011/2012 varsity season), 2 in men's ice hockey, 3 in men's soccer (1 from an athlete who also suffered a previous concussion in the 2011/2012 varsity season), 2 in men's basketball, 1 in women's ice hockey, 3 in women's basketball and 2 female wrestlers (1 from an athlete who also suffered a previous concussion in the 2010/2011 varsity season).

Therefore, over the three-year period, 76 concussions were recorded in University of Alberta varsity athletes: 54 in male athletes and 22 in female athletes. In total, 3 athletes suffered from a second concussion in the same varsity season (all male athletes), and 7 athletes suffered a previous concussion in an earlier season (5 male and 2 female athletes). Because 3 of these athletes (2 male hockey athletes and 1 male soccer athlete) did not have baseline ImPACT testing completed their data was removed, leaving a total of 73 concussions. There were 10 athletes who had multiple concussions in the three-year period and these were only entered once. Of these 10 athletes, only 3 of them went on to receive a new baseline test. Because 7 of the athletes who suffered multiple concussions during the study did not complete a new baseline test and it was thought the 3 athletes with new baseline tests might skew the data, all 10 athletes who suffered multiple concussions were removed from further analyses. This resulted in 63 athletes being included in the final analysis. Overall, during the three seasons, male athletes sustained 51 of these concussions (39 in football, 8 in ice hockey, 5 in soccer and 2 in basketball) and female athletes had 22 concussions (8 in ice hockey and in rugby, 3 in basketball, and 3 in wrestling), with respective incidence rates of 14.6% and 6.3% (Figure 2.0).

In a multivariate logistic regression model, visual memory was the only significant ($p = .031$) risk factor for concussion with an odds ratio of 2.45 (95% CI 1.09 – 5.46). Initially male and female baseline ImPACT composite scores were combined for data analyses. Overall, athletes who were at or below the 10th percentile for visual memory were 2.5 times more likely to have a concussion than athletes who were above the 10th percentile. In a Pearson Chi Square analysis comparing male and female athletes separately, visual memory was a significant (p =.014) risk factor for female athletes who scored below the 10th percentile. A follow up multivariate logistic regression analysis confirmed this finding for females with an odds ratio of 4.40 (95% CI 1.34-14.44). Female athletes who scored below the 10th percentile for visual memory were 4.4 times more likely to sustain a concussion than respondents who were scored above the 10th percentile. In males, none of the baseline composite score from ImPACT at or below the 10th percentile were significant for increased risk for concussion. In multivariate logistic regression models for the post-concussion symptom clusters on PCSS from ImPACT comparing male and female athletes separately none of the clusters were found to be significant as possible risk factors for future concussion.

Multivariate logistic regression models comparing male and female athletes separately for their responses on the questionnaire revealed that a family history of concussion for males was significant (p =.032) with an odds ratio of 0.4 (95% CI 0.17-0.93). Therefore, males with a family history of concussion were less likely of having a future concussion as compared to males in this study that did not have a family history of concussion. This is likely not clinically significant. None of the other variables examined were significant as possible risk factors of future concussion for female athletes.

Data Summary

A relatively small number of athletes reported difficulties on the "other questions" portion of the preseason concussion questionnaire. When athletes were asked: "Have you ever been diagnosed with a learning disability?" only 9 of the 356 (2.5%) athletes who responded said "yes". Similar results were found for athletes diagnosed with attention deficit hyperactivity disorder (ADHD), with only 5 (1.4%) athletes responding "yes". Of the athletes who completed the questionnaire, 13 (3.7%) had been diagnosed with depression by a physician. Athletes who had been diagnosed with a general anxiety disorder (GAD), post-traumatic stress disorder (PTSD) or any other mental health disorder comprised 6 (1.7%), 1 (0.3%) and 3 (0.8%) of the respondents respectively. Sleep disorders were also not reported by very many athletes with only 5 (0.01%) answering "yes" to this question. More athletes reported physical illnesses as opposed to the mental health illnesses listed above. When athletes were asked: "Have you ever experienced migraine headaches?" 86 of the 356 (24.2%) athletes responded "yes". This was the only question that was phrased using "experienced" versus diagnosed by a physician. Many athletes also reported having been diagnosed with asthma by a physician with 60 (16.9%) of the athletes saying "yes".

On the preseason concussion questionnaire, 175 of the 356 (49.1%) athletes reported having suffered a previous concussion. After three varsity athletic seasons, 31 of these previously concussed athletes were diagnosed with a sport-related concussion for an incidence rate of 17.7%. The incidence rate for athletes who had no previous concussion history but who suffered a concussion in this study was 18.3%. These 2 incidence rates are very similar because of the 63 athletes who suffered a concussion in this study, 31 had a previous history of concussion and 32 did not. Many athletes reported having family members with a concussion history (131 of the 356 or 36.8% questioned). Of these 131 athletes, 25 (19.1%) received a sport-related concussion over the three-year period. The incidence rate of concussion for those athletes who did not have a family member with a history of concussion was 29.0%. These were not statistically significantly different either.

Chapter 5

Discussion

The first aim of this study was to determine if athletes' self-report of post-concussion symptoms differed depending on the type of concussion evaluation tool used and the mode of administration. On 13 of the 18 "matched" symptoms, athletes reported greater symptoms on the computerized neuropsychological ImPACT test versus the paper and pencil version of SCAT2. Athletes reported significantly different mean symptom scores on 10 of the 18 "matched" post-concussion symptoms. For 8 of the significantly different mean symptoms scores, athletes reported greater post-concussion symptoms on ImPACT. In 2 of the significantly different cases the mean symptom score was greater on SCAT2.

It is conceivable that the athletes in this study reported differently on the two tools because of the level of relative anonymity afforded by the computerized

ImPACT, as compared with the SCAT2, which is done on paper in the presence of their team therapist. After athletes complete ImPACT, the test is saved on an internal server to be referred to at a later time. Research in social psychology has found that people are more willing to engage in "spontaneous self-disclosure" when using computer-mediated communication versus face-to-face discussions (Joinson, 2011). These subjects experience "visual anonymity" and this may have been one reason why the athletes in the present study reported more post-concussion symptoms on the baseline ImPACT test.

The method of recording symptoms, as well as sex of the interviewer, has been shown to affect test results (Krol et al., 2011). In that study, athletes reported a greater TSS and a greater number of symptoms when using a self-administered post-concussion scale (PCS) versus being interviewed by a team therapist. Social desirability, which is the inclination for an individual to respond to questions in a manner that will be viewed favourably by others, may influence how much information athletes are willing to share (Krol et al., 2011). Athletes also reported more symptoms when the interviewer was female. The presence and characteristics of the interviewer may also influence the type and amount of information athletes share. This may be another reason why athletes in the current study self-reported significantly less symptoms on the SCAT2 when they had to immediately submit their report to a team therapist.

A common method for interpreting change on a post-concussion symptom scale is to use a reliable change index (RCI). This concept can also be applied when comparing two athletes' self-report of post-concussion symptoms as was done in this study. This statistical method uses the standard error of the difference score (ImPACT Applications, 2011). It is important to consider the clinical significance of this type of data as well. If an athlete endorses a high number of symptoms at baseline he/she should have a follow-up examination. There may be a reasonable explanation for the large number of symptoms reported by an individual athlete, such as a particular life stressor at that time. A limitation of this study is that there was no follow-up on athletes who endorsed a high number of symptoms on the computerized ImPACT at baseline. In future, when athletes self-report a large number of post-concussion symptoms at baseline, the neuropsychologist who reviews the test should meet with the athlete and determine why this is occurring.

Some additional limitations arising from the comparison of baseline self-report of post-concussion symptoms may relate to the method of information collection. The paper and pencil version of the SCAT2 was completed with each athlete at the team's practice venue. This may have created environmental distractors as well as time of day issues when the SCAT2 was completed. Some athletes may have completed the SCAT2 prior to practice in a quieter setting, before the whole team arrived, while other athletes may have completed the SCAT2 after practice when they were fatigued. The potential influence of the student therapist who distributed the SCAT2 has been mentioned previously, and this may have also added to variability in responses. Athletes may have felt inclined to downplay baseline post-concussion symptoms because they were aware that their self-report would not be completely confidential. History of a previous concussion can increase post-concussion symptom reporting at baseline (Covassin et al., 2010). In this study almost 50.0% of the varsity athletes had suffered a previous concussion, which may have increased baseline TSS. Thus, differences in the timing of the SCAT2 baseline test, the presence of the student therapist and the potentially confounding history of a previous concussion factor are limitations of this study. In moving forward, all athletes should complete their baseline SCAT2 in a similar manner. For example the baseline SCAT2 tests could be completed when the athletes are scheduled to complete their ImPACT baseline tests, in a quiet environment, and then the SCAT2 results could be submitted into an envelope so the team therapist does not immediately see the self-report of post-concussion symptoms. With the new SCAT3 the post-concussion symptom scale is on the same page as the Standardized Assessment of Concussion (SAC) and the page has to be folded so the athletes cannot see the SAC answers. This may alleviate some anonymity issues in future.

The second aim of this study was to identify potential risk factors from baseline ImPACT composite scores and post-concussion symptom clusters. This study found that the visual memory composite score at baseline, on ImPACT testing did help to identify varsity athletes who went on to suffer a concussion. When analyzed together as a single group, athletes were 2.5 times more likely to suffer a future concussion when they scored at or below the 10^{th} percentile. Females were 4.4 times more likely to suffer a future concussion when they scored at or below the 10^{th} percentile for visual memory. The additional composite baseline scores and post-concussion symptoms clusters from ImPACT were not significantly different for athletes who incurred a concussion than for those who did not. It appears that the visual memory composite score did predict those athletes in this study who went on to suffer a sport-related concussion. The memory composite scores from ImPACT are believed to measure aspects of concentration and memory. In an analysis of convergent validity with the ImPACT composite scores and post-concussion symptoms, the memory composite scores were significantly correlated (r = -0.40) with poor memory and poor concentration (ImPACT Applications, 2011).

In this study, a cut-off score for potential risk factors was set at or below the 10^{th} percentile. By selecting a low cut-off score, identifying fewer athletes at risk would decrease sensitivity, but only identifying those with very low scores would increase specificity. The 10^{th} percentile cut-off score was selected because of its common use in neuropsychological research as a cut-off score indicating impairment (Bonders & Levitt, 2012). The 10^{th} percentile cut-off scores from this study also paralleled the normative scores from ImPACT quite closely, in that an athlete with a score in the 10^{th} percentile would be considered "low average", a term used by ImPACT (Appendix 3.0). Selection of the lowest 10^{th} percentile in this study as a cut-off for potential risk factors may be a limitation.

The cut-off score is an arbitrary point and may have excluded athletes who really were at risk for a future concussion. Interpreting scores from neuropsychological tests relies on five psychometric principles, which are: (1) Low scores are relatively common across all test batteries; (2) Low scores depend on where the cut-off score is set; (3) Low scores vary by number of tests administered; (4) Low scores vary by demographic characteristics of the examinee; and (5) Low scores vary by level of intelligence (Iverson & Brooks, 2011). In this study, all of the above principles are applicable and may have resulted in some athletes who were at risk of a sport-related concussion not being identified by their baseline ImPACT composite scores.

Another possible limitation arising from the use of computerized neuropsychological ImPACT testing may result from the athletes completing the baseline test in a group environment. In a study that examined group versus individual administration of neuropsychological tests, high school athletes scored significantly lower on all composite scores except total symptom score in a group setting (Moser et al., 2011). It is possible that in the current study, the group setting at baseline testing may have been a distraction for athletes, and therefore could have resulted in lower composite scores.

The final aim of this study was to identify potential risk factors for concussion from the preseason concussion questionnaire. Interestingly, male athletes with a family history of concussion were found to be slightly less likely to suffer a sport-related concussion. The study did not find increased odds for a future sport-related concussion for female athletes on any of the potential risk factors.

A major limitation of the preseason concussion questionnaire was that it was never examined for any psychometric properties. The questionnaire was created using current concussion risk factors as identified by the literature, but the validity and reliability were not assessed and this may have contributed to some measurement error. With the preseason concussion questionnaire, similar to the SCAT2, athletes may have been concerned with returning it directly to a student therapist, thus decreasing any anonymity. Social desirability may have again prompted athletes to downplay previous history of injuries or illnesses. Without further analysis of the preseason concussion questionnaire it is difficult to determine the accuracy of the athletes' responses.

When the preseason concussion questionnaire was examined, for the 356 varsity athletes who completed it, fewer variables were significant than were originally hypothesized. This may be due to the fact that very few athletes in this study identified possible problems on the questionnaire, and this prompted a further examination of the incidence rates of these conditions from this study. The number of varsity athletes in contact and collision sports suffering from concussions in this study was also lower than expected. Male athletes sustained 51 sport-related concussions, over the 3 years, and female athletes sustained 22 sport-related concussions, with respective incidence rates of 14.6% and 6.3%. Published epidemiology studies report the rate of concussions in collegiate athletes as much higher than was seen in this study, with concussion rates for male athletes being reported at 45% and rates for female athletes at 38% (Daneshvar et al., 2011). The low incidence rates of previously reported concussions in University of Alberta varsity athletes may be due to recall error or athletes being unwilling to share this negative history because of thinking that it may adversely affect their position on the team.

In this study, very few athletes reported any history in the “other questions” section of the preseason concussion questionnaire. Only 2.5% of varsity athletes reported a history of learning disabilities (LD) and only 1.4% a history of attention deficit hyperactivity disorder (ADHD). The Center for Disease Control and Prevention (CDC) reports that 7.66% of United States children between the ages of 3-17 years old are diagnosed with a LD and 6.69% with ADHD (Retrieved from: http://www.cdc.gov/features/dsdev_disabilities/). As mentioned previously, the low number of responses could be due to perceived social desirability. Again, the questionnaires were completed in a group format, which may have prompted athletes to take the process less seriously and not attend to the questions (Krol et al., 2013).

The current study found that only 3.7% of athletes reported having been diagnosed with depression by a physician. The National Institute of Mental Health (NIMH) states that 30 % of college students reported feeling "so depressed that it was difficult to function" (Retrieved from: http://www.nimh.nih.gov/health/publications/depression-and-college-students/index.shtml). The lower incidence rate of depression in this varsity athlete study could be due to the requirement for an actual diagnosis versus self-reported feelings in the NIMH report. In this study only, 1.7% of the athletes reported having been diagnosed with general anxiety disorder (GAD) by a physician. The NIMH says that GAD affect about 3.1% of American adults aged 18 years and older in a given year and that the average age for onset of GAD is 31 years of age (Retrieved from: http://www.nimh.nih.gov/health/topics/generalized-anxiety-disorder-gad/index.shtml). In this study, none of the varsity athletes were over 28 years of age and this could be part of the reason for the low incidence rate. Only 1 athlete, a female, reported having been diagnosed with posttraumatic stress disorder (PTSD). According to the NIMH, PTSD affects about 7.7 million American adults. It can occur at any age and women are more likely to develop PTSD than men (Retrieved from: http://www.nimh.nih.gov/health/topics/post-traumatic-stress-disorder-ptsd/index.shtml). Depression, GAD and PTSD are difficult topics for athletes to discuss with their team especially if they think it may affect their playing time, and therefore this may lead to the low incidence rates which were reported.

In this study, 17.0% of the varsity athletes reported having been diagnosed with asthma by a physician. In the 2011 National Health Interview Survey (NHIS), it was found that 13.0% of adults aged 18 and over had been told by a doctor or other health professional that they had asthma (NHIS, 2011). Sidiropoulo et al. (2012) reported asthma rates of 15.0% in male football athletes and 13.7% in male basketball athletes. In the current study, asthma incidence rates were similar to those reported in research. The current study found that 24.2% of the athletes had migraine headaches. Kinart et al. (2002) reported that 2.9% of NCAA male and female basketball players have migraine headaches, as determined by the International Headaches Society's (IHS) criteria for headache diagnosis. The current study included only one question on migraine headaches, with no inclusion or exclusion criteria for athletes and this likely contributed to the higher reported incidence rate.

Varsity athletes in this study reported having a family member who had suffered a previous concussion 36.8% of the time. Over the three-year period, 19.1% of the athletes who received sport-related concussions had a family history of concussion. Many researchers have attempted to link genetics as a possible risk factor of concussion. Research has been conducted on the association between Apo lipoprotein epsilon (APOE) genotype and concussion. It is suggested that APOE may play a role in chronic changes due to concussions, but its role in acute concussion is less clear (Makdissi et al., 2013). In the current study, a family history of concussion was a significant risk factor for future concussion only in female athletes. Clearly more research is necessary to determine why there is a risk for concussion in family members and the possible role of specific genes.

Finally, this was one of the first studies to examine baseline concussion testing, using ImPACT composite scores, post-concussion symptom clusters and items from a preseason questionnaire in college athletes to try and determine which athletes would be at risk for a concussion. Risk factors for concussion or prolonged recovery have mostly been researched in the post-injury period, using self-report symptoms (Chrisman et al., 2013). If at risk athletes can be identified during the pre-season, then it may be possible to prevent some of the concussions in these athletes.

Conclusions and Future Research

In this study on varsity athletes in contact and collision sports, there was a significant difference in self-report of post-concussion symptoms on the paper and pencil version of SCAT2 versus the computerized neuropsychological ImPACT test. When performing baseline, post-injury and return to play assessments, sport medicine professionals should ensure that ancillary tests are given in the same form and under the same conditions. Emerging technology and applications for smart phones and tablets provide graded symptom checklists in a variety of locations and manners. An Internet search found 12 different applications for iPads and 18 different applications for iPhones. Thus, it is important to keep abreast of these emerging technologies and applications and the role they may have in concussion awareness.

The computerized neuropsychological ImPACT test was used at baseline in this study and did identify some potential risk factors for future concussion in these contact and collision varsity athletes. A baseline visual memory score below the lowest 10^{th} percentile resulted in an increase in risk for future concussion in both sexes. Post-concussion symptom clusters did not identify any significant risk factors from baseline ImPACT testing in this study. The symptom clusters have identified risk for protracted recovery (≥ 14 days) in high school students in a post-injury time period (Lau et al., 2011). They may have not been significant risk factors for a future concussion in this study because the varsity athletes did not report as many severe symptoms at baseline as compared to post-injury. In future, it would be valuable to take note of athletes whose composite scores and post-concussion symptom clusters are at or below the lowest 10^{th} percentile at baseline. Preventative measures such as technique changes and/or visual or vestibular retraining could be applied to these athletes and discussed with their coaches.

The preseason concussion questionnaire was unable to identify a potential risk factor for future concussions in males. Males who had a family history of concussion were less likely to suffer a future concussion. This was likely a spurious finding. Further research on pre-participation evaluations at baseline is needed to verify these findings, and to look for other potentially predictive risk factors for concussion. This would allow medical and para-medical personnel to educate athletes and coaches on the importance of this injury and possible preventative measures.

The first recommendation for performing baseline testing with the SCAT2 would be to make the post-concussion symptom scale self-reports more anonymous. This could be easily achieved by having athletes return their SCAT2 page to an envelope rather than directly to a team therapist or fold over for the SCAT3 page. Secondly, every effort should be made to have athletes complete their SCAT2 and ImPACT baseline tests prior to physical activity and in a quiet environment free from distractions. Thirdly, a neuropsychologist should review the test scores from baseline testing with the computerized ImPACT and follow-up should be arranged for athletes who score below the 10^{th} percentile. Finally, if accurate baseline information can be recorded for both SCAT and ImPACT, then these tools may be used to help make return to play decisions, but only in conjunction with a clinical examination by a trained sport medicine professional. More research is needed to further ascertain the utility of these tools, including development of more valid pre-season screening questionnaires, to help predict the risk for concussion and institute preventative measures if possible.

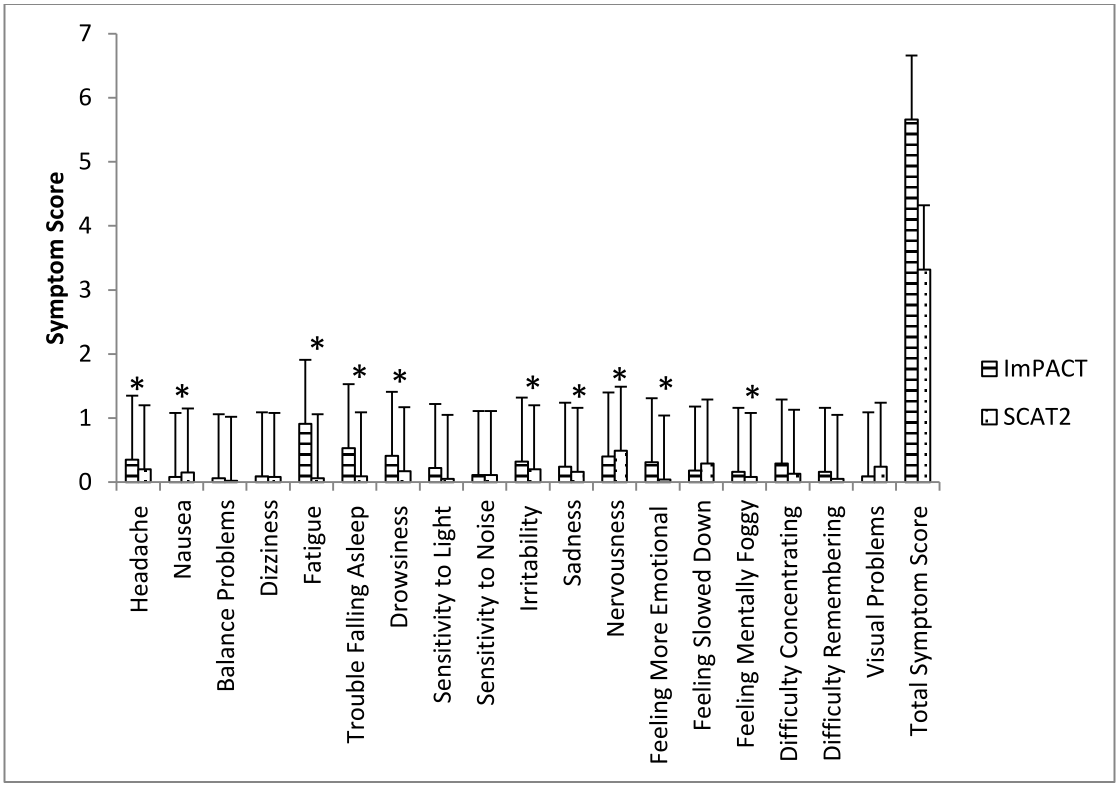

Figure 1.0: ImPACT versus SCAT2 Baseline Self-Report of Post-Concussion Symptoms - Mean Scores (+SD)
* = Significantly different ($p \leq 0.05$)

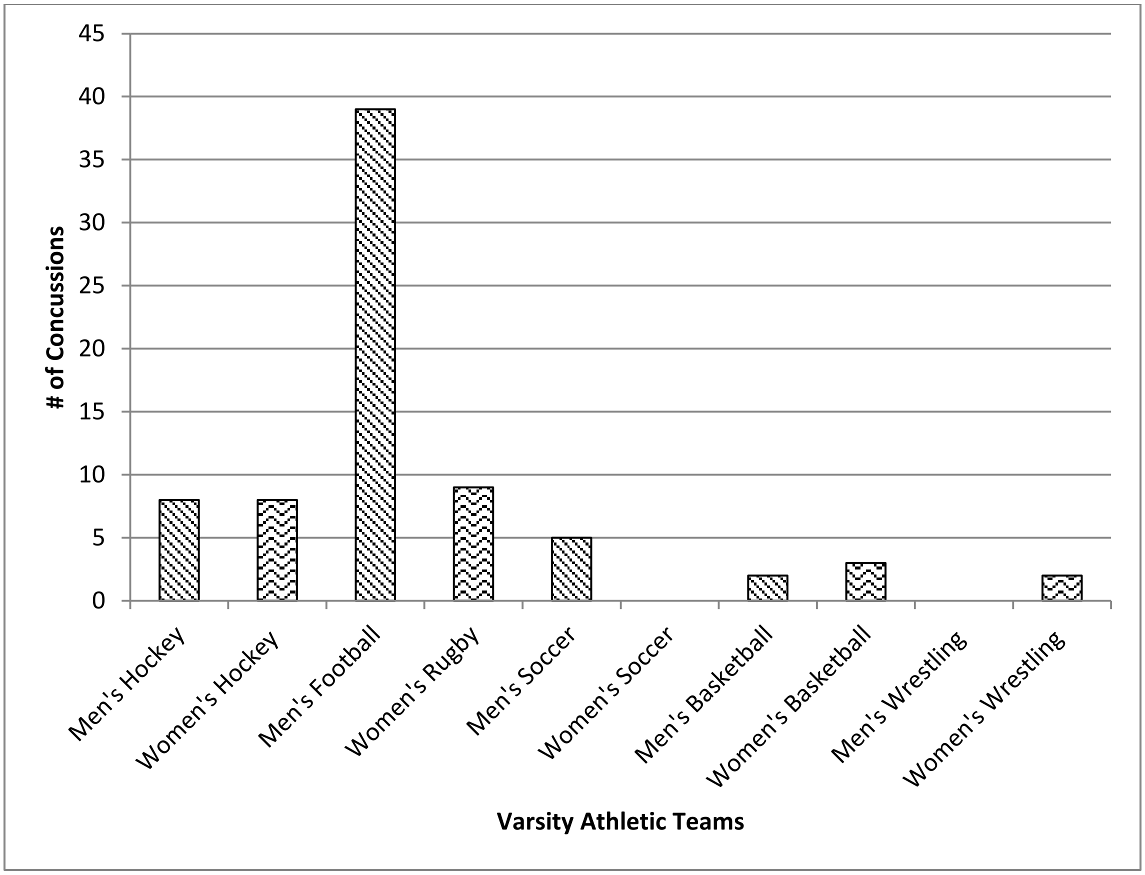

Figure 2.0 Total Number of Concussions by Sport for the Three-Year Period (n=76)

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Appendix 1.0: Preseason Concussion Questionnaire

UNIVERSITY OF ALBERTA

PRESEASON CONCUSSION QUESTIONNAIRE

Please be complete with your answers

General Questions:

Name: ______________________________ Date of Birth: ___________

Age: _______________________________ Weight (pounds): ________

Height: _____________________________ Year in University: ________

Approximate GPA last year: __________

Sport Specific Questions:

1. What sport are you playing at the U of A this year? _______________________

2. How many years have you played this sport? _____________

3. What position do you play? _____________________________

4. Based upon your position, estimate how often you become engaged in physical contact with another player during a typical game?

Never __ Infrequently__ Moderately frequently__ Very frequently__ Continuously__

5. When contacting another player, do you typically think about head placement, engage head first, or do not think about it?

Think about head placement__ Engage head first__ Do not think about it__

6. Relative to your teammates, how would you rate your aggressiveness?

1 (minimal)__ 2(mild)__ 3(moderate)__ 4(very aggressive)__ 5(extreme)__

7. Do you wear a mouth guard when you practice? Yes__ No__

If yes, what type is it?: boil & bite__ stock__ custom__

8. Do you wear a mouth guard when you play a game? Yes__ No__

Concussion/Head Injury

A concussion is defined as any injury that involves a blow to the head that results in any 1 of the following symptoms, no matter how long they last: headaches, dizziness, lack of awareness, nausea, vomiting, disorientation. Later symptoms include any one of the following: headaches, dizziness, poor concentration, memory troubles, irritability, poor sleep, balance problems, depressed mood.

9. Have you had a concussion while playing your current sport at the university level? Yes__ No__

If yes, how many? 1__ 2__ 3__ 4__ 5__ >5__

If yes, were you ever knocked out? Yes__ No__

If you were knocked out, about how long were you unconscious?

A few seconds__ <5 minutes__ 6-15 minutes__ >15 minutes__

If yes, were you hospitalized? Yes__ No__

10. Have you ever had a concussion playing any sport before university? Yes__ No__

If yes, what sport?________________________

If yes, how many? 1__ 2__ 3__ 4__ 5__ >5__

If yes, were you ever knocked out? Yes__ No__

If you were knocked out, about how long were you unconscious?

A few seconds__ <5 minutes__ 6-15 minutes__ >15 minutes__

If yes, were you hospitalized? Yes__ No__

11. Have you ever had a concussion playing any other activity before university? Yes__ No__

If yes, what activity?________________________

If yes, how many? 1__ 2__ 3__ 4__ 5__ >5__

If yes, were you ever knocked out? Yes__ No__

If you were knocked out, about how long were you unconscious?

A few seconds__ <5 minutes__ 6-15 minutes__ >15 minutes__

If yes, were you hospitalized? Yes__ No__

Other Questions:

12. Have you ever been diagnosed with a learning disability? Yes__ No__

If yes, what was the nature of your disability? ____________________________

13. Have you ever been diagnosed with Attention Deficit Hyperactivity Disorder? Yes__ No__

If yes, did you take medication for treatment? Yes__ No__

14. Have you been diagnosed with Depression by a physician? Yes__ No__

If yes, did you ever take medication to treat this condition? Yes__ No__

15. Have you been diagnosed with Generalized Anxiety Disorder by a physician? Yes__ No__

If yes, did you ever take medication to treat this condition? Yes__ No__

16. Have you been diagnosed with Post-Traumatic Stress Disorder by a physician? Yes__ No__

If yes, did you ever take medication to treat this condition? Yes__ No__

17. Have you even been diagnosed with any other mental health condition? Yes__ No__

If yes, did you ever take medication to treat this condition? Yes__ No__

18. Have you ever experienced migraine headaches? Yes__ No__

If yes, did you require medication to treat this condition? Yes__ No__

19. Have you ever been diagnosed with asthma? Yes__ No__

If yes, did you require treatment with medication for this condition? Yes__ No__

20. Have you ever been diagnosed with a sleep disorder? Yes__ No__

21. Do you have parents, brothers, or sisters who have had a concussion?

Yes__ No__

If yes, which family member? ____________; how many have they had? ______

If yes, from a car accident? ________; sports_________; other? ______________

If sports, which one? __________________

Conditioning

22. How long have you been actively conditioning for the upcoming season?
________weeks

How many days per week have you been training (approximately)? ____

How many hours per day have you been training (approximately)? ____

23. Have you completed the Leger (Beep) test of V02 max testing in the last week? Yes__ No__

If yes, what level did you reach (Leger test) ____/ V02 max score: _____

24. Relative to your teammates, how would you rate your level of fitness?

Poor___ Below Average___ Average___ Above Average_____ Excellent___

25. When during a game do you feel you are most at risk for getting a concussion?

Never___ Beginning of a game___ Middle of a game___ End of a game___

26. Why do you feel more at risk for getting a concussion during this part of the game?

Not warmed up?__ Fatigued?__ Poor Concentration?__ Other:__________

Appendix 2.0: Post-Concussion Symptom Clusters (Lau et al., 2011)