The Sport Concussion Assessment Tool in the Management of Concussion in Professional Ice Hockey
TIMO HÄNNINEN

The Sport Concussion Assessment Tool in the Management of Concussion in Professional Ice Hockey

ACADEMIC DISSERTATION
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UNIVERSITY OF TAMPERE
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– jotta baastaisitte itsenne tutkimaan nykyistä ja kirjoittamaan tulevaisuutta
LIST OF ORIGINAL COMMUNICATIONS

This dissertation is based on the following four original peer-reviewed publications, which are referred to by the Roman numerals I–IV. The original communications have been reprinted with the permission of the copyright holders.


Study I is also a part of the doctoral dissertation “Injuries in the International Ice Hockey Federation World Championships and Olympic Winter Games” by Markku Tuominen, M.D.
The purpose of this dissertation was to enhance ice hockey players’ safety by improving the clinical identification and management of acute sport-related concussion. The first step in this process was to identify the magnitude of the problem, and to establish risk factors and injury mechanisms that affect injury occurrences. A large number of international male and female ice hockey players competing at various age and skill levels were analyzed over a nine-season observation period for this study. The injury registry of the International Ice Hockey Federation was used to explore the incidence and typical characteristics of ice hockey-related concussions. It comprised a total of 3,293 games (142,244 athletic game exposures) including 160 concussions in the World Championships and Olympic Winter Games. The study demonstrated an average rate of 7 concussions per 100 games among professional male athletes. The corresponding injury rate for women was 4 per 100 games, and for juniors the rate was 5 per 100 games. However, the annual concussion rate in the men’s tournaments decreased over the study period. Since 2012, the risk of concussion in the men’s tournaments has been lower than in the junior tournaments. Typically, a concussion occurred through contact with another player. A check to the head was the most common cause of injury among male athletes. Almost half of the concussive events occurred near the boards. The risk of concussion associated with board contact decreased significantly when flexible boards and glass were used instead of traditional rink materials.

The second step – toward improved player safety – was to advance the clinical identification of acute game-related concussion. The approach we took was based on the main challenge of the current Sport Concussion Assessment Tool (SCAT). The SCAT is a standardized, clinically applicable tool designed to capture the spectrum of clinical signs and symptoms, cognitive dysfunction, and neurological deficits that often manifest acutely after a concussive injury. However, no valid interpretation guidelines currently exist for the clinical use of the SCAT. The aim was to integrate the findings of what constitutes uncommon performance among uninjured athletes and how concussed athletes perform according to the SCAT measurement on the day of injury. The study design was implemented in a practical manner among professional ice hockey teams in order to maximize the
generalizability and applicability of the results. A representative sample \((n=304)\) of players from the highest Finnish ice hockey league were baseline-tested to obtain league-normative reference values. Next, a large, two-season test-retest sample of players \((n=179)\) were tested to improve our knowledge of the normal variability of change on the SCAT scale. Finally, the sensitivity of each SCAT subcomponent to the acute effects of concussion was examined using the day-of-injury SCAT results of 27 concussed players. Personal baselines and the league’s normative reference values were both utilized in post-injury assessment. We studied whether post-injury SCAT assessment using personal baselines adds value compared to the use of normative reference values.

The evidence from this research suggests that the cutoffs for uncommon performance based on the SCAT components are as follows: Symptom Score=4, Symptom Severity Score=6, Standardized Assessment of Concussion (SAC)=24, Modified Balance Error Scoring System (M-BESS)=6, Tandem Gait=12.9. Furthermore, the following changes from personal baseline values should be considered uncommon: Symptom Score +3 or more, Symptom Severity Score +5 or more, SAC -3 or more, M-BESS +3 or more errors, Tandem Gait +4 seconds or more.

Symptom inventory was the most sensitive SCAT component to discriminate between concussed and uninjured athletes. The most common symptoms among uninjured athletes were “fatigue or low energy” and “neck pain”. They were also the most likely to change between two consecutive baseline tests. By contrast, “Don’t feel right”, “headache”, and “pressure in the head” were the most prevalent post-injury symptoms reported by the concussed players on the day of the injury assessments.

Finally, the two interpretation methods were used. The post-injury scores were compared (i) to the league normative reference values and (ii) to the athletes’ personal baselines. These interpretation methods demonstrated similar levels of sensitivity in distinguishing between concussed and uninjured athletes. Post-injury impairment identification improved if both methods were used simultaneously. Additionally, considering the normal variability within each test and utilizing normative reference ranges rather than a continuous scale seemed to provide additional value for clinical decision-making.
Tämän väitöskirjatutkimuksen tarkoituksena oli tutkia jääkiekossa tapahtuvien aivotärähdysten yleisyyttä, syntymekanismeja ja riskitekijöitä sekä parantaa niiden väliöntiä tunnistamista ja sitä kautta lisätä lajin turvallisuutta. Aivotärähdysten väliönti tunnistaminen on tärkeää, jottei loukkaantunutta urheilijaa altisteta heti uusille ja mahdollisesti vakavammille vammoille. Lisäksi pian vammatapahtuman jälkeen tehty oikea diagnoosi mahdollistaa optimaalisen kuntoutuksen ja vähentää siten todennäköisyyttä pitkittymisiin ongelmiin. Väitöskirjassa käsitellään aihetta erityisesti ammattilaisjääkiekkoilijoiden näkökulmasta.

Aivotärähdyksellä tarkoitetaan liikuntalääketieteessä päähän kohdistuneen suoran tai epäsuoran ulkoisen voiman aiheuttamaa aivojen toiminnan häiriöitä, johon ei liity merkittäviä aivojen rakenteellisia muutoksia. Vamman tunnistamiseen ei ole olemassa yksiselitteistä ja pätevää diagnostista testiä tai -tutkimusta, vaan diagnoosi perustuu kliinikon päätelyyn. ”Sport Concussion Assessment Tool” (SCAT) on kliinikon päätöksenteon tueksi kehitetty arviointityökalu aivotärähdysten akuuttiiin tunnistamiseen. Se sisältää systemaattisen oirekyselyn lisäksi muun muassa kognitiivisten muutosten seulantasten sekä tasapaino- ja koordinaatiotutkimuksia.


Oirekysely oli SCAT:in osasteisteista herkin ja tarkin erottelemaan vammapäivänä testatut urheilijat terveistä urheilijoista. Yleisimmät oireet vammapäivänä olivat päänsärky ja ”paineentunne päässä”. Vastaavasti yleisimmät oireet, joita terveet urheilijat ilmoittivat perustasomittauksissa, olivat ”väsymys tai voimattomuuden tunne” sekä niskakipu. Näiden oireiden osalta myös vaihtelu peräkkäisten perustasomittausten välillä oli suurinta.

Vammanjälkeisten tulosten tulkinnassa käytetty kaksi menetelmää: (i) vertailu liigan normatiiviarvoihin ja (ii) henkilökohtaiseen perustasoon olivat yhtä herkkä tunnistamaan urheilijat terveistä. Vamman tunnistus kuitenkin paranii, kun menetelmä käytettiin rinnakkain. SCAT-tulosten normaalivaihtelun ja liigan normatiivivuokkien raja-arvojen tunteminen vaikuttaisi tehostavan työkalun kliinistä käytettävyyttä.
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Finally, I dedicate this dissertation to my beloved wife and sons. Boys, you are my sunshine. Seeing you two great researchers of life every single day training and achieving the skills needed in SCAT – but also increasing your knowledge of senses and symptoms simultaneously – makes me feel privileged and fortunate. Maiju, thank you for standing by my side. No matter whether I scored the golden goal or just got benched, you have always been there for me. Thank you!
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<tr>
<td>ADHD</td>
<td>Attention deficit hyperactivity disorder</td>
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<tr>
<td>AUC</td>
<td>Area under the receiver operating characteristic curve</td>
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<tr>
<td>ChildSCAT</td>
<td>Sport Concussion Assessment Tool – Edition for sport participants aged 5–12 years</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
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<td>CIS</td>
<td>Concussion in sport</td>
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<tr>
<td>d</td>
<td>Cohen’s d value</td>
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<tr>
<td>EEG</td>
<td>Electroencephalographic</td>
</tr>
<tr>
<td>FTN</td>
<td>Finger-to-nose</td>
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<td>ICC</td>
<td>Intraclass correlation</td>
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<td>IIHF</td>
<td>International Ice Hockey Federation</td>
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<tr>
<td>IQR</td>
<td>Interquartile range</td>
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<tr>
<td>IR</td>
<td>Injury rate</td>
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<tr>
<td>LOC</td>
<td>Loss of consciousness</td>
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<tr>
<td>M</td>
<td>Mean</td>
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<tr>
<td>M-BESS</td>
<td>Modified Balance Error Scoring System</td>
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<tr>
<td>Md</td>
<td>Median</td>
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<tr>
<td>M.D.</td>
<td>Doctor of Medicine</td>
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<tr>
<td>mTBI</td>
<td>Mild traumatic brain injury</td>
</tr>
<tr>
<td>n</td>
<td>Sample size</td>
</tr>
<tr>
<td>N/A</td>
<td>Not available / not applicable</td>
</tr>
<tr>
<td>NHL</td>
<td>National Hockey League</td>
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<tr>
<td>p</td>
<td>p-value, probability value</td>
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<tr>
<td>PocketSCAT2</td>
<td>Sport Concussion Assessment Tool – Edition for non-medically trained persons</td>
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<tr>
<td>R</td>
<td>Range</td>
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<tr>
<td>ROC</td>
<td>Receiver operating characteristic</td>
</tr>
<tr>
<td>RTP</td>
<td>Return to play</td>
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<tr>
<td>SAC</td>
<td>Standardized Assessment of Concussion</td>
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<tr>
<td>SD</td>
<td>Standard deviation</td>
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<tr>
<td>SM-Liiga</td>
<td>Finnish Ice Hockey League</td>
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<tr>
<td>TG</td>
<td>Tandem Gait</td>
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Sports participation improves not only the athlete’s physical skills, but also his or her mental and cognitive skills, such as learning and spatial memory (Hillman, Erickson & Kramer 2008, Cassilhas et al. 2012). Ice hockey is a sport with rapid changes in the direction of movement that require the athlete to develop a high level of dynamic balance control and postural stability (Stein, Zehr & Bobet 2000). Furthermore, improved visuomotor skills, better attentional focus, and enhanced task-switching abilities are potential brain plasticity-related human performance advantages achieved as a result of ice hockey training (Adkins et al. 2006). Despite its many health benefits, ice hockey also carries a risk of injury. The most commonly injured body region of professional male ice hockey players is the head. In particular, concussion is a trauma that often leads to missed participation for a period of days, weeks, or even months after injury (McKay et al. 2014b, Tuominen et al. 2015). Early recognition of the injury is essential, because those athletes who are not withdrawn from the rink immediately after concussion are associated with an increased risk of subsequent injuries and prolonged recovery (Guskiewicz et al. 2003, Brooks et al. 2016, Asken et al. 2016).

The current theory of concussion pathophysiology emphasizes acute neurological dysfunction rather than significant structural damage (McCrory, Berkovic 2001, Giza et al. 2014, King et al. 2014, McCrory et al. 2017a). Although some recent studies have demonstrated that the physiological perturbations in a specific neuroanatomical location can be linked to some clinical characteristics of concussion (Giza, Hovda 2014), the objective gold-standard diagnostic measurements remain deficient. As a result, the diagnosis of sport-related concussion still relies on the clinician’s subjective judgement.

The fifth International Consensus Statement on Concussion in Sport recommends the use of a standardized multi-modal clinical test battery, the Sport Concussion Assessment Tool (SCAT), in the acute assessment of athletes with suspected concussion (McCrory et al. 2017b). The recognition of acute concussion leading to immediate removal from play reduces the likelihood of consecutive (Guskiewicz et al. 2003) and more serious intra-cranial injuries (Giza et al. 2014) as well as the risk of subsequent non-head injuries (Herman et al. 2015, Lynall et al.
Early identification of the injury and correct diagnosis allows the appropriate return-to-play protocol to be initiated, reducing the risk for prolonged recovery (Asken et al. 2016, Elbin et al. 2016, Schneider et al. 2017). However, no formal SCAT interpretation guide has been published, leaving clinicians to develop their own interpretive approach. If we can integrate the information establishing what constitutes uncommon performance among uninjured athletes and the typical acute post-injury findings for concussed athletes, we may be able to better understand the proper use and interpretation of day-of-injury SCAT scores (Meeuwisse 2009).

The general aim of this dissertation was to enhance the clinical identification and management of acute sport-related concussions. Specifically, I sought to create an evidence-based methodology for interpreting the acute post-injury scores of the SCAT in clinical settings among professional ice hockey players. An additional emphasis of the dissertation was to improve awareness of the typical characteristics of concussions in ice hockey.
2  REVIEW OF THE LITERATURE

2.1  Concussion in ice hockey

2.1.1  Definition of concussion

Concussion is a traumatically induced brain injury caused by a direct or indirect external impulsive force applied to the head resulting in a complex pathophysiological process. A concussion disrupts brain function and can manifest in several ways, including the alteration of neurological, neurocognitive, vestibular, oculomotor, attention, or mental functions. A variety of signs and symptoms can be observed post-injury that evolve over time, seemingly without any other explanation, and no structural abnormality is seen in standard structural neuroimaging studies. Due to the absence of an objective, gold-standard criterion, the diagnosis of sport-related concussion relies heavily on the clinician’s judgement. A multifaceted approach to diagnosis can often help identify impairments caused by the injury. This approach typically combines different assessment techniques, such as symptom evaluation, neurological status, cognitive function, and balance control. In addition, the injury mechanism must be considered if it has the potential to result in a concussive injury. “Concussion” is a commonly used term in international sports medicine literature. It is a sub-set of “traumatic brain injury,” thought to be placed on the less severe end of the injury severity spectrum. For the most part, “concussion” overlaps with the definitions “mild traumatic brain injury” (mTBI) and “commotion cerebri” (McCrory, Berkovic 2001, Giza et al. 2013, Harmon et al. 2013, McCrory et al. 2017a).

2.1.2  Pathophysiology of concussion

forces to the head determine the mechanical response of the brain to the impact, and they can vary widely in amplitude, direction, and location. Impulsive head motion results in acceleration loading to the brain. Inertial forces, especially shear forces generated by rotational acceleration, deform the brain tissue; these forces are considered the predominant mechanism to induce concussion. By contrast, the brain is highly resistant to a transient increase in pressure caused by linear acceleration. However, high-energy direct contact forces to the head causing mostly linear acceleration are related to skull fractures and focal brain injuries. These injuries are more common in more severe brain injuries, but can also occur during a concussion (Meaney, Smith 2011, Blennow, Hardy & Zetterberg 2012).

When neural elements and vascular tissue within the brain are exposed to mechanical stimulation (e.g., shearing strain), a series of metabolic events may lead not only to cellular dysfunction or apoptosis, but also to a disruption in the plasticity of cellular networks. A neurometabolic cascade resulting from a concussion is thought to be initiated by sudden axonal stretching and the deformation of neuronal membranes that result in alterations in ionic shifts. This leads to a calcium-mediated neuronal and axonal ion imbalance. Depolarized neurons further increase the release of excitatory neurotransmitters, leading to spreading and diffuse neuronal depression. Mechanoactivated alterations in the properties of synaptic neurotransmitter receptors and the balance of excitation/inhibition receptor compositions may also be reasons for the abnormal response of neurons to subsequent stimulation. Glucose consumption is increased when the cell tries to re-establish homeostasis. Specifically, in order to restore cellular homeostasis, more glucose is required to provide energy for Na-K pumps, but altered cerebral blood flow induced by cerebral dysautoregulation prevents adequate glucose delivery. Furthermore, an influx of calcium into the cellular mitochondria leads to impaired oxidative metabolism, thus generating an imbalance of energy supply and demand. Other important components of post-concussion pathophysiology include the generation of lactic acid, the production of free radicals, decreased intracellular magnesium, and widespread inflammatory responses. Accumulation of intracellular calcium may also activate direct pathways to apoptosis and impair neural connectivity by disrupting axonal neurofilaments and microtubules (Giza, Hovda 2001, Blennow, Hardy & Zetterberg 2012, Giza, Hovda 2014, Barkhoudarian, Hovda & Giza 2016). Figure 1 illustrates a hypothesis of the molecular changes following a rotational acceleration loading to the brain that leads to concussion. In conclusion, differences in the forces applied to the head and its position at the moment of impact result in a variable brain response to impact. This makes each
concussion unique, and explains the variable clinical presentation with the diffuse and fluctuating manifestation of injury signs and symptoms.

**Figure 1.** Hypothesized molecular pathophysiology of concussion (Reprinted with permission: Blennow et al. 2012).
2.1.3 About ice hockey

Ice hockey is a contact sport played while skating on a rink of ice enclosed within wooden or plastic boards that are commonly topped with protective plexiglas or a similar material. According to the International Ice Hockey Federation (IIHF) rulebook, the recommended dimensions of an ice hockey rink are 60 meters by 30 meters, and the rink has rounded corners. Each ice hockey team typically consists of 18 to 22 players. Both teams normally have two wingers, one center, two defensemen, and a goaltender on the ice at the same time during a game. The active playing time is three periods of 20 minutes (IIHF 2014).

The equipment is similar for all ice hockey players, except for facial protection. Male players over 18 years old are allowed to wear partial facial protection (a visor). All others must wear full facial protection, a strategy that has been shown to decrease the risk of eye and facial injuries (Stuart et al. 2002). The main difference between male and female ice hockey rules is that intentional body checking is not permitted at any level of women’s ice hockey. The removal of body checking is an effective rule change to reduce the risk of concussion in youth ice hockey (Emery et al. 2010, Emery et al. 2011). Checking from behind is against the rules at all levels of ice hockey, due to the association between this behavior and the high risk of head and neck injuries (Watson, Singer & Sproule 1996).

The IIHF is the governing body of international ice hockey. It has 77 member national associations with approximate 1.8 million players. The IIHF controls the international rulebook and dictates the officiating guidelines. It coordinates the annual IIHF World Championships at all skill levels for men, women, and juniors competing at the Under-20 and Under-18 levels. The IIHF is also responsible for ice hockey at the Olympic Winter Games [http://www.iihf.com/iihf-home/the-iihf/ (accessed July 2017)]. The Finnish Ice Hockey League (the SM-Liiga) is the highest men’s ice hockey league in Finland. It operates independently from the Finnish Ice Hockey Association. It consists of 15 professional teams (14 teams during the 2013–2014 and 2014–2015 seasons). The SM-Liiga follows the international rulebook [www.liiga.fi/ (accessed May 2017)]. The National Hockey League (NHL) is the highest level of professional male ice hockey in North America.
2.1.4 Epidemiology of ice hockey-related concussions

The incidence of sport-related concussion ranges between 6 and 8 per 100 regular-season games in the NHL (Hutchison et al. 2015a, Echemendia et al. 2017a). However, it is difficult to compare injury rates across different concussion studies due to the lack of consistent research methodologies. Specifically, the diagnostic criteria, data collection techniques, and reporting of outcome measures vary widely across the literature. Furthermore, the differences in study samples (e.g., one team versus all teams in a league), the observation period (e.g., tournament games, regular-season games, pre-season, or practice), the length of data collection, and the level of competition might be factors associated with the large range of variation in the published incidence rates of ice hockey-related concussions. In order to simplify inter-study comparisons in this dissertation, the different study results have been adjusted. This adjusted injury rate (IR) format calculates the number of injuries per 100 games (= #injuries / #games x 100). Within this format, all athletes participating in a game, regardless of the duration and type of exposure, are fixed at the same risk of concussion during a 60-minute game. Furthermore, much lower injury rates have been reported in ice hockey during practices compared to games at the high school, collegiate, and professional levels (Flik, Lyman & Marx 2005, Kuzuhara, Shimamoto & Mase 2009, Agel, Harvey 2010, Marar et al. 2012).

Systematic injury data collection of all teams in the NHL revealed that the IR for concussion, diagnosed according to the prevailing Consensus Statement on Concussion in Sport by team physicians, was 8.2 during the 2013–14 and 2014–15 seasons (Echemendia et al. 2017a). From the beginning of the 2006–7 season until the end of December 2009, the IR was 6.1 (Hutchison et al. 2015a). Furthermore, the IR was 5.9 during the regular 2002–3 and 2003–4 seasons (Benson et al. 2011). A slightly lower IR for concussion is provided if published media reports are used as the source of injury data (e.g., 4.6 per 100 games during the regular 2005–6, 2006–7, and 2007–8 seasons of the NHL) (Wennberg, Tator 2008). Smaller rinks and a more physical style of play are considered the reasons for North American leagues showing a higher percentage of concussions in relation to the overall number of injuries compared to leagues using the international rules (Wennberg 2004, Ruhe, Gansslen & Klein 2014). A cohort study of one Swedish elite-level team, with the same team physician making all the concussion diagnoses across the seasons, found the IR ranging from 4 to 18 per 100 games (mean=11) from the 2006–7 to the 2012–13 seasons (Pauelsen et al. 2017). Another similar study setting at a lower competitive level – among one Japanese elite team with the majority being amateur players –
found an IR of 3 per 100 games during the 2002–3, 2003–4, and 2004–5 seasons (Kuzuhara, Shimamoto & Mase 2009). Individual factors may also play a role in concussion injury risk. For example, gender may influence the ice hockey-related concussion risk (Schick, Meeuwisse 2003, Hootman, Dick & Agel 2007), but recent work has identified a non-significant association between these factors (Agel, Harvey 2010, Kerr et al. 2016, Zuckerman et al. 2016). Regarding juniors, the rates of concussion among collegiate and high school ice hockey players are reported to be similar (Marar et al. 2012) or slightly higher (men: 9 per 100 games; women: 10 per 100 games) (Agel, Harvey 2010) than the reported rates in the NHL (Hutchison et al. 2015a, Kerr et al. 2016).

2.1.5 Typical features of ice hockey-related concussions

Player-to-player contact in which a taller and heavier opponent hits the lateral aspect of the injured player’s head with his shoulder is a typical injury mechanism for a concussion among professional male ice hockey players (Hutchison 2011). The studies by Hutchison and colleagues (2015a, 2015b) offer probably the most comprehensive analysis of injury mechanics in professional ice hockey. They analyzed the video records of 197 diagnosed concussions in the NHL. When fighting-related injuries (n=16/197) were excluded, they found that 87% (n=158/181) of the concussions occurred as a result of direct contact with an opponent. Most of these contacts involved an initial hit to the player’s head (108/158), especially to the lateral aspect of the head (74/108). Of the player-to-player contacts resulting in concussion, 62/158 caused a head motion in both the sagittal and transverse planes. Concussion-related hits were often delivered by the opponent’s shoulder (66/158). Hutchison and colleagues (2015a) also identified that the average player delivering the contact leading to a concussion was taller (mean +1.3cm, 95% CI = 0.2–2.3, p=0.02) and heavier (mean +3.6kg, 95% CI = 2.19–4.98, p<0.01) than the average player who sustained a concussion. Furthermore, a case-by-case analysis revealed that 52% of the injured players were smaller and 65% were lighter than the player who delivered the contact. A study by Bruce and colleagues (2017), in which the injury mechanism data of all cases with visible signs of concussion in NHL games during the 2013–14 and 2014–15 seasons were coded from the video records, supports the findings that an initial hit to the head by an opponent’s shoulder is highly associated with the increased likelihood of a following concussion diagnosis. In addition, secondary contact between the player’s head and
the ice was a significant risk factor for concussion. By contrast, the absence of secondary contact – as well as stick-related initial contact – were associated with a decreased risk for a subsequent concussion diagnosis among those players with visible signs of a suspected concussion.

In a number of studies, playing position was associated with a risk of concussion when on-ice proportional representation was considered. Many studies agree that goaltenders are at a much lower risk for concussion than other players (Flik, Lyman & Marx 2005, Benson et al. 2011, Izraelski 2013, Hutchison et al. 2015a), while several published studies suggest that the injury risk of forwards is higher than that of defensemen (Goodman, Gaetz & Meichenbaum 2001, Flik, Lyman & Marx 2005, Hutchison et al. 2015a, Pauelsen et al. 2017). In particular, the incidence of concussion among center players is considered relatively high (Benson et al. 2011). However, a recent study of NHL players did not find a statistically significant risk difference between the forwards and defensemen (Izraelski 2013). When the position on the rink during the injurious event is considered, relatively even distributions of concussions are located on the open ice and perimeter (i.e., near the boards). However, only 21% of all these injuries occurred between the blue lines (the neutral zone). Almost half of the concussions among defensemen (45%) occurred in the defensive zone, especially when retrieving the puck from behind the net. By contrast, forwards had relatively equal injury rates across the different playing zones, and they were often injured when “on the rush” (Hutchison et al. 2015a).

Previous studies among NHL players have revealed a correlation between concussion and an athlete’s time on the ice per game. In a study conducted by Stevens and colleagues (2008), those who spent more than an average of 15.22 minutes (the median value) on the ice per game had an increased likelihood of suffering a concussion. However, the total time on the ice for the season was not a predictor of concussion. In a more recent study (Izraelski 2013), the 60-minute active game time was divided into intervals of 5 minutes. An average time on the ice ranging from 15 to 20 minutes was a significant predictor of concussion, although the same study stated that most of the players in the NHL spend 15 to 20 minutes on the ice per game. The author suggested that the underlying mechanism is the interaction between the average time on the ice and the player’s skill levels or playing profile, rather than fatigue accumulated during the activity (Izraelski 2013). Unlike the general trend in other ice hockey injuries, in which most injuries occur during the second period (Tuominen et al. 2015), the majority (47%) of concussions sustained in the men’s elite-level games occur in the first period (Hutchison et al. 2015a). Furthermore, unexpected falls, accidental trips, and unintended collisions are
uncommon causes of concussion in men’s professional ice hockey (Hutchison et al. 2015a). Undoubtedly, these findings also challenge the association between the risk of concussion and fatigue.

2.2 Acute assessment of concussion in sport

There is a consensus among sports medicine scientists that concussion assessment protocols should be based on a multidimensional (Figure 2) and multi-timed approach to evaluation (Harmon et al. 2013, McCrory et al. 2017b). Through the initial examination, if an extremely low likelihood of more serious brain injury is determined on the field/court, the athlete with a suspected concussion should be removed from play for a more detailed sideline evaluation (Fuller et al. 2017). Self-reported symptom scales, questionnaire-based cognitive screening, and clinician-rated balance testing are all brief but essential pieces of assessment that can be easily conducted on the sideline (Patricios et al. 2017). In addition, several objective diagnostic measures exist that are designed to reduce diagnostic and tester bias, quantify the initial magnitude of neuronal injury, and enable a more accurate prognosis (Smith et al. 2017). Currently, there is a large selection of different concussion assessment methods, including technological innovations, which may offer additional value to the currently recommended combination of sideline assessment tests. The Sport Concussion Assessment Tool (SCAT) (Patricios et al. 2017), and its most recent version (SCAT5), is currently the internationally recommended test of choice in sideline assessment.

More detailed descriptions of the different types of concussion assessment methods other than the SCAT are outside the scope of this dissertation. However, the following references can be used to find more information on blood-based biomarkers for brain injury (Shahim et al. 2014, Shahim et al. 2017); functional neuroimaging (Brandstack 2013); quantitative electroencephalography (EEG) (Barr et al. 2012, Prichep et al. 2013); computerized neurocognitive evaluation tools (Collie, Darby & Maruff 2001); head impact sensor systems (Smith et al. 2017, Patricios et al. 2017, Brennan et al. 2017); sensorimotor tests (Murray et al. 2014); oculomotor tests (Galetta et al. 2015a, Hunt et al. 2016); screening tests for the vestibular system (Kontos et al. 2017); and visuomotor reaction time tests (Eckner et al. 2014).
2.3 The Sport Concussion Assessment Tool (SCAT)

The SCAT is a standardized, periodically re-evaluated concussion screening instrument for the acute assessment of athletes with a potential concussion. The first International Conference on Concussion in Sport (CIS) was organized in 2001 by the International Ice Hockey Federation, the Federation Internationale de Football Association Medical Assessment and Research Centre, and the International Olympic Committee Medical Commission. A range of experts were invited to share their knowledge at the conference to improve the safety and health of athletes who suffer concussive injuries in sports. The delegates and organizing bodies gave a mandate to a small group of experts, named the Concussion in Sport Group, to draft a summary and agreement statement (Aubry et al. 2002). Following the second conference in 2004, the SCAT was published as part of the summary and agreement statement. The SCAT is a clinically applicable tool for clinicians to capture the
spectrum of clinical signs and symptoms, cognitive dysfunction, and neurological
deficits that often accompany a concussion. This structured combination of
assessments is based on expert consensus of the best measures currently available to
assess concussion (McCrory et al. 2005). The third International CIS Consensus
Conference in 2008 was carried out via a formal consensus process that adhered to
the guidelines of the National Institutes of Health. The SCAT2, an improved version
of the tool, was produced. It was designed for medical practitioners to enable a more
detailed sideline assessment of concussion. Additionally, the PocketSCAT2, a
version of the tool for non-medically trained persons, was launched (McCrory et al.
2009). The Fourth CIS Consensus Conference in 2012 updated the SCAT2 to the
SCAT3 without altering the major components (symptoms, cognitive and balance
assessment) in the revision. The PocketSCAT2 was updated to the Concussion
Recognition Tool. Furthermore, a modified version of SCAT3 (ChildSCAT3) was
released for the post-injury evaluation of sports participants aged between 5 and 12
years (McCrory et al. 2013). A recent systematic review supports the use of a separate
evaluation tool for young athletes, as age-related variation in SCAT3 performance is
apparent among younger athletes (Yengo-Kahn et al. 2016).

The Fifth International Consensus Conference on CIS was held in Berlin in
October 2016 (Meeuwisse et al. 2017). The revision of the SCAT3 to SCAT5
(Appendix 4) was made as a part of the consensus process. Only necessary evidence-
based modifications were made to insure the continuity of the tool. A few relevant
modifications concerning the sideline assessment (i.e., the SCAT components
included in this study) were made. First, in the SCAT5 the athlete should be
instructed to report baseline symptoms according to how the athlete “typically” feels,
not how the athlete feels at the time of testing. Second, additional sets of words and
numbers for the Standardized Assessment of Concussion (SAC) were produced,
including an option to use a list of ten words instead of five in immediate and delayed
word recall. Third, the timing of the flawless Tandem Gait task was replaced with
only an observer’s subjective evaluation of whether the athlete performs the test with
or without any error. In addition, the Finger-to-nose coordination task is no longer
timed. Finally, more standardized instructions to complete the SCAT components
were provided (Echemendia et al. 2017b). In the following chapters, the detailed
content of the SCAT will be discussed and the current key literature on each SCAT
subcomponent will be summarized accordingly.
2.3.1 Medical history

Based on a review written by the consensus group, concussion history is a risk factor for future concussions and delayed recovery (Makdissi et al. 2013). In line with this review, an NHL study concluded that the recovery period increased 2.3 times (95% CI = 1.4–3.6) for every subsequent concussion sustained (Benson et al. 2011). By contrast, in a study with collegiate athletes, self-reported concussion history was not associated with clinical outcome (e.g., return-to-play time) (Putukian et al. 2015). Thus, the method used to obtain concussion history (e.g., self-report versus medical history) seems to have some effect on the study results. It has also been suggested that concussed athletes are in general more injury prone than their controls – i.e., they have a higher risk for injury both before and after sustaining the index concussion (Burman et al. 2016). The SCAT includes self-reported information on previous concussions (Appendix 2). This method of obtaining an athlete’s concussion history is not highly reliable (Valovich McLeod et al. 2008, McKay et al. 2014a) and may cause bias. Apart from concussion recovery, prior concussion can have a lingering effect on symptom reporting (Brooks et al. 2013). Most studies suggest that self-reported concussion history has no significant effect on the overall SCAT baseline performance (Valovich McLeod et al. 2012, Zimmer et al. 2015, Chin et al. 2016), but athletes with previous concussions may report more baseline symptoms than their non-concussed peers (Shehata et al. 2009, Valovich McLeod et al. 2012).

Athletes with attention-deficit/hyperactivity disorder (ADHD) tend to report a greater number and higher severity of baseline symptoms listed in the SCAT compared to athletes without ADHD. In addition, they perform worse on the M-BESS and get lower SAC scores on average. Furthermore, a self-reported learning disorder is related to worse performance on the SAC, and seems to predict higher symptom ratings when compared to athletes who do not report such a disorder (Chin et al. 2016). Substantial disagreement between methods of obtaining the medical history has also been found for those reporting learning disorders (McKay et al. 2014a).

Migraine headache, depression, and anxiety are other factors reported in the SCAT that may modify concussion-related outcomes. These conditions may be triggered by a head trauma or they may co-occur with concussion. Clinically distinguishing between concussion and post-injury migraine may be difficult. However, all of these modifiers should be considered when interpreting post-injury SCAT performance and planning post-injury rehabilitation. They are suggested to...
be risk factors for prolonged recovery (Gordon, Dooley & Wood 2006, Morgan et al. 2015, Perry et al. 2016, Eckner et al. 2016, Hixson et al. 2017). When it comes to the SCAT, a positive screening of anxiety or depression is associated with higher baseline Symptom Scores (Putukian et al. 2015).

2.3.2 Injury-related information

A multimodal concussion evaluation process requires an accurate description of the injury mechanism (Bruce et al. 2017). The SCAT3 provides only a space to write it down (Appendix 2). However, the injurious event is not always observed by the clinician, so defining the mechanism of injury using a video review contributes to the better identification of meaningful head impact events (Fuller et al. 2017).

Potential signs of concussion, including loss of consciousness (LOC), amnesia, disorientation or confusion, balance or motor incoordination, and a blank or vacant look, should be observed and documented on the SCAT form (Appendix 2). The presence of these signs is an indication of a potential concussive or more severe injury (Benson et al. 2011, Echemendia et al. 2017a). Finding multiple signs together increases the likelihood of a concussion diagnosis. However, the overall sensitivity of these signs on their own is low. For example, more than half of the physician-diagnosed concussions in the NHL occur without the presence of any potential visual signs (included in the SCAT) of concussion. Furthermore, visible signs such as “slow to get up” and “clutching of the head” can be observed frequently following a direct or indirect hit to the head in the NHL, but only a small number of these cases result in a clinically diagnosed injury (Echemendia et al. 2017a). Combining the data of the injury mechanism with the visible signs enhances the sensitivity and specificity of the findings (Bruce et al. 2017).

A recent study reporting the video review findings of 202 game-related concussions in the NHL during the regular 2013–4 and 2014–5 seasons revealed that post-injury LOC was present in 13 (6%) of the cases (Echemendia et al. 2017a). This is the same rate as published when a population of concussed mixed-sports high school and collegiate athletes were studied using data from post-injury SCAT3 forms (Chin et al. 2016). By contrast, the injury report system data from previous NHL seasons (1997–8 to 2003–4) with the current diagnostic criteria demonstrated the presence of post-injury LOC in 18% of the concussion cases (Benson et al. 2011). A brief LOC does not reflect the severity of the injury or predict a prolonged recovery (Makdissi et al. 2013).
Post-injury amnesia (either antero- or retrograde) was experienced by 21% of NHL players with a concussion, and it was also a significant predictor of a prolonged return to play (Benson et al. 2011). Similarly, one-fifth of the concussed mixed-sports high school and collegiate athletes has been reported to have post-injury amnesia. Half of these athletes suffered from anterograde amnesia and the other half from retrograde amnesia (Chin et al. 2016).

Acute coordination or balance problems were found in 35/202 (17%) cases when concussion-related deficiencies were detected in NHL video reviews. The same study recorded a blank or vacant look in 4/202 (2%) cases. The video records were not able to reveal any disorientation related to these concussion cases (Echemendia et al. 2017a).

2.3.3 Symptom evaluation

Symptom evaluation is a sensitive but not specific assessment for concussion, likely due to the non-specific nature and subjective format of these inventories. Athletes rate their symptoms on the SCAT’s graded 22-item symptom checklist. The checklist items are based on results from clinical neuropsychology (Alla et al. 2009). The symptom scale provides a systematic structure to document the total number and severity of symptoms. The Symptom Score ranges from 0 to 22. The Symptom Severity Score is the sum of 7-point Likert ratings (0–6) for the entire scale and thus ranges from 0 to 132. Higher scores indicate a larger symptom burden (Appendix 2).

Both the face validity of the SCAT symptoms and their strong reliability and sensitivity for concussion support the use of the symptom scale in the acute evaluation of athletes with possible head trauma (Lovell et al. 2006, Alla et al. 2009, Guskiewicz et al. 2013, Putukian et al. 2015, Patricios et al. 2017). For example, in high school and collegiate athletes participating in contact and collision sports (n=166), acute post-injury Symptom Severity Scores could reliably discriminate the concussed from the non-concussed. In this particular study, the Symptom Severity Score resulted in a large effect size (d=1.52) and the area under the receiver operating characteristic curve (AUC) was 0.86 for the raw score and 0.88 for the baseline-adjusted score (Chin et al. 2016).

It is important to understand that concussion symptoms are also present among uninjured individuals (Shehata et al. 2009). In college athlete populations, almost half (48%) endorsed at least one SCAT symptom, and 2% reported 10 or more symptoms.
when assessed prior to the beginning of the season (Zimmer et al. 2015). A summary of the reported SCAT baseline symptoms of selected studies is presented in Table 1.

**Table 1.** Average numbers of baseline symptoms reported among different populations

<table>
<thead>
<tr>
<th>Population (athletes)</th>
<th>n</th>
<th>Age (years)</th>
<th>Mean</th>
<th>SD</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>University ice hockey</td>
<td>25 males 20 females</td>
<td>1.5–3.2</td>
<td>Echlin et al. 2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>College mixed-sports</td>
<td>330 males</td>
<td>18–23</td>
<td>1.7</td>
<td>2.9</td>
<td>Zimmer et al. 2015</td>
</tr>
<tr>
<td>College mixed-sports</td>
<td>176 males 87 females</td>
<td>Mean=20</td>
<td>1.5</td>
<td>2.4</td>
<td>Putukian et al. 2015</td>
</tr>
<tr>
<td>High school mixed-sports</td>
<td>72 males</td>
<td>16–19</td>
<td>2.6</td>
<td>3.4</td>
<td>Jinguji et al. 2012</td>
</tr>
<tr>
<td>High school mixed-sports</td>
<td>872 males</td>
<td>Mean=16</td>
<td>5.3</td>
<td>5.3</td>
<td>Valovich McLeod et al. 2012</td>
</tr>
</tbody>
</table>

When college male contact and collision sports athletes (n=875) were studied, four symptoms represented the cutoff for a below-average score (<25% of the sample). The cutoff for an uncommon Symptom Score (<10% of the sample) was seven symptoms, and less than 2% of the sample endorsed 12 or more symptoms (Chin et al. 2016). Furthermore, the 10th percentile cutoff for a mixed-sports collegiate athlete population of 176 males and 87 females was five symptoms (Putukian et al. 2015). By contrast, none of the professional male ice hockey players in an NHL team (n=27) reported any baseline symptoms (Galetta et al. 2013).

The mean baseline Symptom Severity Score for mixed-sports collegiate athletes was two (SD=5, Md=0, n=263, mean age 20) (Putukian et al. 2015), and for contact and collision sports athletes in the high school and collegiate population, the mean was five (SD=7, n=2,018, mean age 18, male sex 77%) (Chin et al. 2016). The study reported the following Symptom Severity cutoff scores for college male contact and collision sports athletes (n=875): below average (<25%) cutoff=6, uncommon (<10%) cutoff=11, and extremely high (<2%) cutoff=23 (Chin et al. 2016). The study concerning mixed-sports collegiate athletes found a Symptom Severity Score of 6 to be the cutoff for uncommon (<10%) performance (Putukian et al. 2015).
The most commonly reported baseline symptoms include “fatigue or low energy,” “difficulty concentrating,” “trouble falling asleep,” and “drowsiness.” By contrast, reporting baseline symptoms such as “feeling like in a fog,” “nausea or vomiting,” and “blurred vision” is very rare (Shehata et al. 2009, Jinguji et al. 2012, Zimmer et al. 2015).

Self-reported symptoms significantly increase, with a large effect size, in the initial post-concussion assessment (Broglio, Puetz 2008, Putukian et al. 2015). The mean number of acute post-injury symptoms endorsed was nine (SD=5) and the mean post-injury Symptom Severity Score was 19 (SD=17) among the mixed-sports collegiate athlete population (n=176 males and 87 females). Of the concussed athletes, 88% reported an uncommon number of symptoms (the worst 10th percentile baseline cutoff in the population was five symptoms) and 81% had uncommon Symptom Severity Scores (score ≥6) (Putukian et al. 2015). The mean post-concussion Symptom Severity Score for high school and collegiate athletes (n=166) in contact and collision sports was 25 (SD=18) when assessed within 24 hours post-injury (Chin et al. 2016). In the study concerning one NHL team, two players were concussed during the observation period. One injured player endorsed 19 symptoms with a severity score of 27 and the other reported six symptoms with a total severity score of 9 in an acute sideline assessment (Galetta et al. 2013).

The most commonly reported acute post-concussion symptoms among professional ice hockey players include headache (71%), “don’t feel right” (69%), “feeling like in a fog” (65%), “feeling slowed down” (51%), “pressure in head” (47%), and drowsiness (42%) (Benson et al. 2011).

The symptom evaluation relies on the accurate reporting of symptoms by the athlete. Athletes report more baseline symptoms when rating themselves compared to a clinician’s interview (Iverson et al. 2010, Krol et al. 2011). By contrast, some athletes may under-report post-injury symptoms to accelerate their return to play or because they misinterpret their condition (Benson et al. 2011, Krol et al. 2011). Athletes in non-contact sports report significantly more baseline symptoms than those participating in collision or limited-collision sports (Zimmer et al. 2015). In addition, athletes who report a shorter duration of sleep during the night prior to baseline testing tend to report more symptoms (McClure et al. 2014), further supporting the notion of the non-specific nature of concussion symptom inventories. Previous research has established that female athletes report more baseline symptoms than male athletes (Lovell et al. 2006, Shehata et al. 2009, Schneider et al. 2010, Covassin et al. 2012). However, most (Jinguji et al. 2012, Valovich McLeod et al. 2012, Zimmer et al. 2015) but not all (Chin et al. 2016) of
the recent evidence suggests that there is not a significant difference between genders when the SCAT symptom scale is used.

Concussion symptoms resolve within 10 days post-injury on average (McCrory et al. 2017b). However, a wide range of individual differences in symptom recovery time exists. More symptoms at the initial post-injury evaluation is significantly associated with prolonged recovery and a delayed return to play (Makdissi et al. 2013, Putukian et al. 2015, Iverson et al. 2017). On average, time loss increased 1.9 times (95% CI = 1.5–2.3) for each additional post-concussion symptom reported in the NHL cohort. Headache and “low energy or fatigue” were especially significant predictors of prolonged time loss (Benson et al. 2011).

2.3.4 Standardized Assessment of Concussion (SAC)

The SAC is a brief, validated (McCrea et al. 1998, Barr, McCrea 2001, Guskiewicz et al. 2013) cognitive screening test designed to detect the prominent acute deficits associated with concussion. It consists of four major components: orientation, concentration, immediate memory, and delayed memory. The SAC total score ranges from 0 to 30, where higher scores reflect better performance (McCrea, Kelly & Randolph 1996, McCrea, Kelly & Randolph 2000). Additionally, the SCAT5 includes an option to use a list of 10 words (instead of five words used in SCAT3) in the immediate and delayed memory components. This results in a total score range of 0–50 (Appendix 4). The SAC is not intended as a substitute for formal neuropsychological evaluation, but as a sideline screening tool for clinicians to determine the presence and severity of acute gross neurocognitive impairments (Echemendia et al. 2013).

The mean of the SAC baseline scores has varied between 25 and 27 among mixed-sports high school athletes (Jinguji et al. 2012, Valovich McLeod et al. 2012, Chin et al. 2016) and between 27 and 28 in mixed-sports collegiate populations (Putukian et al. 2015, Zimmer et al. 2015, Chin et al. 2016). Studies concerning ice hockey players exclusively reported a mean SAC score of 26 for juniors (range=25–30, mean age=18 years, n=67) (Echlin et al. 2010) and a mean SAC score of 28 for NHL players (range=25–30, mean age=29, n=27) (Galetta et al. 2013). The 10th percentile normative cutoff score (=limit for uncommon performance in the current dissertation) was 26 in the mixed-sports collegiate population (n=176 males and 87 females) (Putukian et al. 2015) and 24 among male collegiate contact and collision sports athletes (n=875) without ADHD and learning disorder (Chin et al. 2016).
same study reported a cutoff score of 25 for “below average” performance (<25% of normative sample) and 22 for “extremely low” performance (<2% of normative sample) (Chin et al. 2016). In addition, the following means of each subcomponent were reported concerning all collegiate athletes (n=1,205): Orientation M=4.9 (SD=0.3), Immediate memory M=14.4 (SD=0.9), Concentration M=3.4 (SD=1.1), Delayed Recall 4.3 (SD=0.9) (Chin et al. 2016). In high school athletes, younger individuals tend to perform worse in baseline cognitive tasks, especially in the concentration component (Jinguji et al. 2012, Yengo-Kahn et al. 2016). In addition, female participants seem to perform better than their male counterparts in the SAC (Zimmer et al. 2015, Yengo-Kahn et al. 2016, Chin et al. 2016).

The discrimination between concussed and control athletes in acute post-injury SAC assessment has been poor (AUC=0.56–0.68) in mixed sex and sports samples (Galetta et al. 2013, Chin et al. 2016). Furthermore, post-injury changes to the SAC have demonstrated either a non-significant difference between healthy and injured groups (Putukian et al. 2015) or a small effect size (d= -0.4) (Chin et al. 2016). By contrast, when male high school and collegiate football players have been studied exclusively, the SAC has demonstrated a high sensitivity to concussion within the first 48 hours following injury. On average, football players had a 2–4-point lower post-injury score compared to baseline, and a drop of one point was 94% sensitive and 76% specific to concussion (Barr, McCrea 2001, McCrea 2001, McCrea et al. 2003). Finally, some concussion studies have suggested that the practice effect influences SAC performance, because uninjured controls have demonstrated improved SAC scores at a follow-up examination compared to the initial baseline (McCrea 2001, Putukian et al. 2015, Chin et al. 2016). However, systematically and more frequently repeated administration of the test did not elicit a significant practice effect (Valovich, Perrin & Gansneder 2003).

2.3.5 Modified Balance Error Scoring System (M-BESS)

M-BESS is a clinical measure of static balance and postural stability. This inexpensive test is easy and rapid to administer in sideline settings (Guskiewicz 2001). It consists of three different stance conditions: standing feet together (double-leg stance); standing on the non-dominant foot (single-leg stance); and standing with the dominant foot directly in front of the non-dominant foot (tandem stance). Each position is performed on a hard surface with eyes closed and hands on hips for a 20-second trial. The maximum number of errors possible is 10 for each stance.
Detailed definitions of the stability errors that the examiner records is presented on the SCAT form (Appendix 2).

A number of published studies suggest that all athletes are able to complete baseline testing without any error in the double-leg stance (Riemann, Guskiewicz & Shields 1999, Finnoff et al. 2009, Jinguji et al. 2012). The single-leg stance has been shown to have high interrater (ICC=0.83–0.93) (Riemann, Guskiewicz & Shields 1999, Finnoff et al. 2009) and intrarater reliability (ICC=0.88) (Finnoff et al. 2009). By contrast, the tandem stance has only moderate intrarater reliability (ICC=0.77, 95% CI=0.57–0.88) and low interrater reliability (ICC=0.44, 95% CI=0.22–0.65) (Finnoff et al. 2009).

Normative data for 20–39-year-old men, women, and both sexes combined have shown the average number of errors in M-BESS ranging from 2.5 to 2.9 (Md=2) (Iverson, Koehle 2013). A baseline study with a sample of male ice hockey players (mean age=18, n=67) reported a mean of 4.3 errors on the M-BESS. Respectively, the mean for baseline errors among mixed-sports high school and collegiate athletes varied between 3.1–4.5 (Jinguji et al. 2012, Putukian et al. 2015, Zimmer et al. 2015, Chin et al. 2016). Among male collegiate contact and collision sports athletes, the cutoff score for “uncommon” performance (<10% of normative values) was six, “below average” (<25% of normative values) was four, and an “extremely high” number of errors (<2% of normative values) was nine (Chin et al. 2016). In addition, another study reported that 90% of mixed-sports varsity athletes scored less than eight errors in M-BESS baseline testing (Putukian et al. 2015).

Concussed athletes scored a significantly (effect size d=0.46) higher number of day-of-injury M-BESS errors than control athletes. Furthermore, both raw and baseline-adjusted M-BESS scores could discriminate between injured and uninjured athletes in acute post-injury assessment (AUC=0.6) (Chin et al. 2016). In a study with a mixed-sports varsity population, 34% of the concussed athletes had “uncommon” post-injury performance – i.e., they scored more errors than 90% of athletes at baseline (Putukian et al. 2015).

Published studies have suggested that females perform better than males (Jinguji et al. 2012, Valovich McLeod et al. 2012, Chin et al. 2016) and also that females and males perform similarly (Iverson, Koehle 2013, Zimmer et al. 2015) in M-BESS baseline testing. Differences between testing environments (Onate, Beck & Van Lunen 2007, Rahn et al. 2015) and examiner agreement in error identification (Zimmer et al. 2013) can affect the results. In addition, the sport and team of an athlete may affect M-BESS performance (Zimmer et al. 2013). Repeated administration of M-BESS is likely to be associated with practice effects (Valovich,
Review of the literature


2.3.6 Tandem Gait (TG)

The TG task in SCAT3 is a timed assessment intended to measure dynamic balance and lower limb coordination (Schneiders et al. 2008). The athlete walks with an alternate foot heel-to-toe gait back and forth along a 3-meter long sports tape. The best time of four correctly done trials is retained (Appendix 2). In SCAT5, the timing of the flawless TG task is replaced with the observer’s subjective evaluation of whether the athlete performs the test with or without any error (Appendix 4).

The TG task has demonstrated high test-retest reliability (ICC=0.7–1.0) (Schneiders et al. 2008, Schneiders et al. 2010a, and 2010b). The post-concussion TG time seems to worsen significantly from baseline (Galetta et al. 2015b) and the cutoff value of 14 seconds seems to have a high degree of specificity to concussive injury (Howell, Osternig & Chou 2017). However, a wide range of variation in the TG baseline times exists among athletes aged from 16 to 37 years. The average time reported in previous studies varies from 11.0–11.8 seconds up to 13.8–16.6 seconds. Furthermore, the range of TG baseline times varies between 5.9 and 26.3 seconds (Schneiders et al. 2008, Schneiders et al. 2010a, Galetta et al. 2015b).

The learning effect (Schneiders et al. 2008, Schneiders et al. 2010a), preceding exercise (Schneiders et al. 2008), and the use of footwear when performing the test enhance the baseline TG times significantly (Schneiders et al. 2010b). The nature of sporting groups studied and the surface on which the task is performed may also influence the time (Schneiders et al. 2010b). The addition of a concurrent cognitive task increases the complexity of the TG test, and may allow the detection of deficits for a longer duration of time after concussion compared to the SCAT3 version of the test (Howell, Osternig & Chou 2017). However, age and gender have not been shown to affect baseline TG performance among athletes aged between 16 and 37 years (Schneiders et al. 2010a).
2.3.7 Finger-to-nose (FTN) coordination task

The coordination examination in the SCAT3 is based on the athlete’s ability to perform five successive FTN repetitions correctly within 4 seconds when sitting with eyes open. Failing this screening test is scored as 0 and successful performance is scored as 1 (Appendix 2). The FTN task is no longer timed in SCAT5 (Appendix 4).

The timed FTN task has demonstrated moderate to excellent reliability (intra-rater ICC=0.7–0.9) (Swaine, Sullivan 1993, Schneiders et al. 2008, Schneiders et al. 2010a). The mean baseline time for a healthy mixed-sex population aged between 15 and 37 years was 2.7–3.6 seconds (Swaine et al. 2005, Schneiders et al. 2008, Schneiders et al. 2010a, Sullivan et al. 2011). The rate of healthy physically active persons with a baseline time of 4 seconds or longer ranges between 6 and 10 percent (Sullivan et al. 2011) Similarly, Jinguji and colleagues (2012) reported that 90 percent of uninjured high school athletes were able to successfully complete the timed FTN task.

The factors that have a statistically significant effect on the FTN baseline time include tested upper limb side (Swaine et al. 2005, Schneiders et al. 2010a); the learning effect (Swaine et al. 2005, Schneiders et al. 2008, Schneiders et al. 2010a, Sullivan et al. 2011); testing position – sitting versus lying; eye condition – open versus closed (Swaine et al. 2005); physical characteristics (Schneiders et al. 2010a); and intensity of preceding exercise (Sullivan et al. 2011). The significance of gender on FTN time is equivocal (Swaine et al. 2005, Schneiders et al. 2008, Schneiders et al. 2010a). However, all the above-mentioned factors are unlikely to have a clinically important impact on the sensitivity of the 4-second time limit in the screening settings (Swaine et al. 2005, Schneiders et al. 2010a, Sullivan et al. 2011). The presence of an upper limb injury should not be ignored when interpreting the test in clinical settings (Schneiders et al. 2010a). Age (range=15–37 years) was not a significant predictor of FTN task time (Swaine et al. 2005, Schneiders et al. 2010a, Sullivan et al. 2011).
2.4 Combining SCAT findings for the clinical diagnosis of concussion

Combining the findings of each SCAT3 component (not the composite score but each component scored independently) results in higher sensitivity and specificity to concussion than using any one component alone (Broglio, Puetz 2008, Guskiewicz et al. 2013, Patricios et al. 2017). In order to capture the diverse and variable spectrum of abnormal brain function associated with concussion, the acute assessment should be multidimensional and multi-timed (McCrory et al. 2017b). Simultaneous assessment of several functional dimensions usually improves the test sensitivity at the expense of specificity. However, sequential multimodal assessments with properly selected items results in both high sensitivity and specificity (Doubilet, Cain 1985).

Two primary approaches to interpreting SCAT data exist in the literature and in practice. Post-injury performance can be compared to the athlete’s individual pre-injury baseline data if available. Comparing the post-injury scores to published normative data is the alternative or complementary method (Schmidt et al. 2012). This approach has demonstrated statistically equivalent sensitivity and specificity to the baseline-adjusted evaluation (Putukian et al. 2015, Chin et al. 2016). It has been proposed that a decline in performance higher than 1.0 SD from the mean warrants caution in terms of returning the athlete to play, and a decline greater than 1.5 SD below the mean is indicative of a real impairment (Zimmer et al. 2015). Combining the two interpretation methods enables clinicians to account for individual modifiers – e.g., language skills (Bruce et al. 2014) – and to evaluate the athlete’s effort (Resch et al. 2013, Zottoli, Hoover & Barr 2015) and other sources of performance validity (Chin et al. 2016). It is also important to note that the pretest probability of concussion will strongly influence the interpretation of sideline screening test results (Akobeng 2007); therefore, combining the post-injury SCAT scores with the data of the injury mechanism is essential (Bruce et al. 2017).
3 AIMS OF THE STUDY

The general aim of this dissertation was to enhance players’ safety in ice hockey. In particular, the aim was to improve the clinical identification and management of acute sport-related concussion and create evidence-based guidelines for the Sport Concussion Assessment Tool interpretation. Additional emphasis was applied on improving the awareness of typical characteristics of ice hockey-related concussions. The specific aims are:

1. To study the incidence, injury characteristics, and time trends of concussions in international ice hockey. *(Study I)*

2. To determine SCAT3 normative reference values for professional male ice hockey players with a focus on cutoff scores for uncommon performance among uninjured athletes. *(Study II)*

3. To examine the test-retest reliability of the SCAT3 baseline assessments for two consecutive seasons to better understand the uncommon change in the scores among uninjured athletes. *(Study III)*

4. To characterize the clinical utility of individual SCAT3 baseline scores and league normative reference values for the assessment of post-injury performance, in addition to identifying the sensitivity of each SCAT3 subcomponent for the acute effects of concussion. *(Study IV)*
4 MATERIALS AND METHODS

4.1 Research process and dissertation structure

This dissertation consists of two parts. The first part is based on a co-authored original contribution (Study I) that describes the incidence, injury characteristics, and time trends of concussion in international ice hockey. Previous studies on international ice hockey injuries (Tuominen et al. 2015, 2016 and 2017) indicate that concussion is one of the most common ice hockey-related injuries to have a considerable impact on player health and safety. In order to provide a more detailed analysis of this specific injury, Study I was conducted. The study is also part of the doctoral dissertation of Markku Tuominen, M.D. (dissertation title: Injuries in the International Ice Hockey Federation World Championships and Olympic Winter Games). The second part of the dissertation consists of three original contributions (Studies II, III, and IV). Collectively, these studies aimed to create evidence-based recommendations for interpreting post-injury performance using the Sport Concussion Assessment Tool (SCAT) among professional ice hockey players. Ethics approval for the studies was obtained from the Ethics Committee of Pirkanmaa Hospital District, Tampere, Finland (code: R13070).
4.2 Part 1: The incidence and injury characteristics of concussion in international ice hockey

4.2.1 Study design and participants

International Ice Hockey Federation (IIHF) uses a standardized injury reporting system to register all injury diagnoses, made by the team physicians, in the IIHF World Championships and Olympic Winter Games. All game-related concussions registered between the 2006-2007 and 2014-2015 (from 1 July 2006 to 30 June 2015) seasons were included in this observational registry study. During the observation period, a total of 3,293 games were played in 169 tournaments by 1,212 teams with 26,130 players comprising 142,244 athletic game exposures (Table 2).

All data for this register-based study has been collected entirely anonymously. Thus, no separate ethics approval was required. The holder of the register (IIHF) has given a written permission for the study.

<table>
<thead>
<tr>
<th>Tournament group</th>
<th>Number of Games</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Men highest level</td>
<td>1,199</td>
</tr>
<tr>
<td>Men’s Under-20 highest level</td>
<td>725</td>
</tr>
<tr>
<td>Boy’s Under-18 highest level</td>
<td>631</td>
</tr>
<tr>
<td>All Women and Girls highest level</td>
<td>738</td>
</tr>
<tr>
<td>Girls’ Under-18</td>
<td>265</td>
</tr>
<tr>
<td>Total</td>
<td>3,293</td>
</tr>
</tbody>
</table>

Table 2. The distribution of the games included in Study I.
4.2.2 Data collection process

Two standardized injury reporting forms were used for data collection. First, the Game Injury Report form (Appendix 1) was used to verify the number of injuries per team. Each team physician delivered a Game Injury Report to the IIHF Medical Committee after each game. Second, the team physician was required to complete an Injury Report System form (Figure 3), with detailed information on the diagnosis, mechanism, anatomic site, period, ice location, and severity for every injury. As soon as all the sufficient information had been obtained and the final diagnosis was confirmed, the anonymous Injury Report System forms were submitted to the IIHF Medical Committee for data insertion into a computer-based injury report system for ice hockey injuries (Medockey, Medisport Ltd, Finland).

**Figure 3. Injury Report System form.**
The IIHF medical supervisor assigned to each tournament was responsible for the data collection. During a team medical personnel meeting before each tournament, the injury reporting process was identified and the supervisor reviewed the definition of each injury. Concussion was defined as a clinical diagnosis made by a team physician. In addition, the team physicians were advised to follow the current Consensus Statement on Concussion in Sport. All concussions had to be reported.

4.2.3 Adjustments for result reporting

In order to simplify inter-study comparisons, the injury rates (IR) were expressed as the number of concussions per 100 games (#concussions / #games x 100 = concussions per 100 games) in the current dissertation. The injury rate was based on a 60-minute active game. Depending on the current level and year of a given tournament, the number of players participating in a game was 20–22 for each team. All athletes, regardless of the duration and type of exposure, were fixed to the same risk of concussion when the IR was calculated. To conclude, IR in the current dissertation is the average risk of a concussion occurring in 100 games. In addition, odds ratios (and/or risk ratios) with 95% confidence intervals were calculated to determine the association between concussions and hypothesized risk factors.
### 4.3 Part 2: Interpreting the SCAT among professional ice hockey players

#### 4.3.1 Study design and participants

SCAT baseline testing has been mandatory for all players in the highest Finnish professional male ice hockey league since the 2013–14 season. The league recommends day-of-injury SCAT testing for all players with suspected concussion. However, there is no requirement to do the baseline test annually, and each team has an independent concussion protocol – i.e., a common practice for team medical personnel to conduct follow-up tests with potentially injured athletes. Thus, only some of the teams completed day-of-injury SCAT testing and administered preseason baseline tests for all athletes for the two consecutive years. More detailed information on the players participating in each part of the study process is presented in Tables 3 and 4. The SCAT3 baseline tests administered for the 2013–14 season were included in the cross-sectional descriptive study determining normative reference values (Study II). Most of the players in the league who were not included in this study were already baseline tested prior to the 2012–13 season. The athletes with preseason SCAT3 baseline data from both the 2013–14 and 2014–15 seasons were included in the cross-sectional descriptive two-season test-retest study (Study III). Most of the players in the league who were not included in this study had only one SCAT3 baseline score. Of the reported day-of-injury SCAT3 tests for the 2013–14 to 2015–16 seasons, a total of 29 concussion diagnoses were made for 27 different players. Two players had two concussions. Only the first concussions of these two players were included in the prospective post-injury cohort study sample (Study IV).

<table>
<thead>
<tr>
<th>Potential participants</th>
<th>Realized participants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Normative reference values</strong></td>
<td>n=427 players in the league during the 2013-14 season</td>
</tr>
<tr>
<td><strong>The two-season test-retest sample</strong></td>
<td>n=309 players in the league for both the 2013-14 and 2014-15 seasons</td>
</tr>
<tr>
<td><strong>A day-of-concussion SCAT3</strong></td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 3. Athletes included in each study.
Materials and methods

### Table 4. Sample characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Normative reference values (Study I)</th>
<th>Two-season test-retest sample (Study II)</th>
<th>Day-of-concussion sample (Study III)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of athletes</td>
<td>304</td>
<td>179</td>
<td>27</td>
</tr>
<tr>
<td>Age</td>
<td>M=25, SD=5, R=16–40</td>
<td>M=25, SD=5, R=16–38</td>
<td>M=27, SD=4, R=19–35</td>
</tr>
<tr>
<td>Finnish players in the sample</td>
<td>87%</td>
<td>96%</td>
<td>81%</td>
</tr>
<tr>
<td>Race: Caucasian</td>
<td>All</td>
<td>All</td>
<td>All</td>
</tr>
<tr>
<td>Athletes with self-reported concussion history</td>
<td>60%</td>
<td>56%</td>
<td>88%</td>
</tr>
<tr>
<td>Prior hospitalization or neuro-imaging following head trauma</td>
<td>20%</td>
<td>18%</td>
<td>22%</td>
</tr>
<tr>
<td>Number of different examiners</td>
<td>22</td>
<td>33</td>
<td>14</td>
</tr>
<tr>
<td>Athletes with the both SCAT3 tested by same person</td>
<td>N/A</td>
<td>36%</td>
<td>44%</td>
</tr>
<tr>
<td>Days between the two tests</td>
<td>N/A</td>
<td>Md=364, M=367, SD=24, R=177–432</td>
<td>Md=79, M=127, SD=122, R=1–560</td>
</tr>
</tbody>
</table>

Note: M=Mean, Md=Median, SD=Standard deviation, R=Range.

Additionally, return-to-play times and acute potential signs of concussion (loss of consciousness, balance/motor incoordination, disorientation/confusion, loss of memory, or blank or vacant look) were confirmed by each team’s medical staff. The median time to RTP was 8 days (Mean=21, SD=48, range=4–248) with 33% of the players remaining out of play for more than 10 days. One or more potential signs of concussion were observed in 10 (37%) cases.

### 4.3.2 Data collection process

In an effort to replicate how the SCAT assessment is given clinically, the teams’ current medical staff administered both baseline and post-injury testing individually to each player in accordance with the SCAT instructions (Appendix 2). Furthermore, demographic variables and medical history were based on the athlete’s self-reported baseline information included in the background section of the SCAT3 form. All athletes with a history of prior concussion were required to demonstrate full recovery.
Materials and methods

The Sport Concussion Assessment Tool in the Management of Concussion in Professional Ice Hockey

from the injury and participate for at least one month in normal game play before they were baseline tested. The final diagnosis and return-to-play day were recorded for each injured athlete by the team physician. The Finnish translation of the SCAT3 (Appendix 3) was used with Finnish players; all others were tested in English. The translation was performed by a professional translator and reviewed by the researchers to maintain the original denotation and connotation of items instead of the exact literal or syntactical equivalence. At the beginning of the 2013–14 season, the medical staff of each team was given training on how to properly administer the SCAT3. Respecting the Guideline for Good Clinical Practice (ICH 1996), each participating athlete provided their written informed consent according to the Declaration of Helsinki.

4.3.3 Statistical analyses

Descriptive statistics [mean (M), median (Md), standard deviation (SD), interquartile range (IQR), and range] for the SCAT3 components were calculated in each study. Variable distribution normality was assessed with the Kolmogorov–Smirnov and Shapiro–Wilk tests. The relationships between potential modifying background variables and the SCAT components were examined in each study. Because of skewed distributions in all components, the correlations between two continuous variables were measured using the Spearman’s rho coefficient, Kendall’s tau b, and the Wilcoxon signed-rank test. Categorical variables in relation to continuous variables were tested with the non-parametric Mann–Whitney U test, and associations between categorical variables were examined using Pearson’s chi-squared test. The number of family-wise comparisons made in the studies was rather small, so the probability of false positive (type I error) results arising was considered to be small. Consequently, no statistical corrections for possible type I errors were carried out. Statistical significance was set at $p<0.05$. Additionally, Cohen’s d was used to estimate effect sizes. In Study IV, receiver operating characteristic (ROC) curves were calculated for each SCAT component to examine the classification accuracy for injured and uninjured athletes. First, post-injury scores (n=27) were compared to the preseason 2013–14 baseline scores of uninjured players (n=283). Second, baseline-adjusted post-injury scores (n=27) were compared to the test-retest difference scores of the uninjured players (n=159) tested at baseline prior to both the 2013–14 and 2014–15 seasons. All athletes who did not speak Finnish or English as a native language were excluded from all statistical analysis concerning the
symptoms (score and severity) and SAC scores. Furthermore, athletes with a diagnosis other than concussion (n=4 of 31) were excluded from the post-injury statistical analyses in Study IV.

4.3.4 Cutoff ranking and change score determinations

The cutoffs for normative ranges determined in Study II were selected based on conventions commonly used in cognitive assessments of normative distributions (e.g., Wechsler classifications). Because of skewed distributions in the scores, cutoff scores were made in approximation to conventional methods. The goal was to select a “below/above average” cutoff corresponding to the worst 25th percentile ranks, an “unusually low/high” cutoff corresponding with the worst 10th percentile ranks, and an “extremely low/high” cutoff corresponding with the worst 2nd percentile ranks. The classifications are worded differently based on the direction of the scoring for the SCAT3 component. The individual differences between the test-retest results of the SCAT3 components were calculated in Study III. The distributions of these change scores were analyzed combining the cutoff scores corresponding to the worst 10th and 5th percentile ranks of change with the findings of the midmost 90% range of scores (Figure 4). In Study IV, the individual post-injury-to-baseline change score (“baseline-adjusted post-injury score”) was calculated by subtracting the players’ most recent preseason baseline score from the day-of-injury score. In addition, the two-season test-retest change score (“test-retest difference score”) was calculated by subtracting the first season baseline score from the second season baseline score. This was done to illustrate normal test-retest variability in the sample, and to ensure that test-retest variability among the current sample of participants was similar to the variability reported for the league.
Materials and methods

The Sport Concussion Assessment Tool in the Management of Concussion in Professional Ice Hockey

<table>
<thead>
<tr>
<th>SCAT3 component</th>
<th>Worse score</th>
<th>Similar score</th>
<th>Better score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test-retest difference score</td>
<td>20 10 7 6 5 4 3 2 1</td>
<td>0 1 2 3 4 5 6 10 20 30</td>
<td></td>
</tr>
<tr>
<td><strong>Symptom Score</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- mean=0.2 better, median=0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- rank worse n=44, better n=55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Symptom Severity Score</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- mean=0.3 better, median=0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- rank worse n=45, better n=57</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SAC total</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- mean=0.4 better, median=0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- rank worse n=54, better n=74</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>M-BESS total</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- mean=0.3 better, median=0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- rank worse n=49, better n=79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tandem Gait</strong> (seconds)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- mean=0.1 better, median=0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- rank worse n=17 better n=17</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

% of players <5% ≤10% 90%

O=different examiner x=same examiner

Note: Athletes who had the exact same score (test-retest difference score=0), better score (fewer symptoms; more points in the SAC; fewer errors on the M-BESS; faster time in Tandem Gait), and a worse score during the second baseline. Worse 10% and 5% in gray. Midmost 90% in dotted line box.

**Figure 4.** The distributions of individual test-retest absolute difference scores.
4.3.5 Integration of the findings

The information on uncommon performance among uninjured athletes (Studies II and III) and the knowledge of typical acute post-injury findings (Study IV) was combined to create evidence-based recommendations for day-of-injury SCAT score interpretation. When the sensitivities of the post-injury measurements were analyzed, normative cutoffs corresponding with the worst 10\textsuperscript{th} percentile ranks (Study II) and test-retest difference scores corresponding to the cutoffs for the worst 10\textsuperscript{th} percentile ranks (Study III) were selected as the limit of “uncommon” performance. The 10\textsuperscript{th} percentile was selected in an attempt to improve sensitivity and maintain specificity at a reasonable level. A possible 10\% false positive rate was considered acceptable in order to detect a possible concussion-related deficit in each component of the SCAT3.
5 SUMMARY OF THE RESULTS

5.1 The incidence of ice hockey-related concussions

The incidence of concussion was 7 per 100 games among professional (men’s pool-A) athletes in the ice hockey World Championship tournaments and Olympic Winter Games over the nine-season observation period (Study I). The incidence ranged between 4 and 7 per 100 games in tournaments for women, juniors, and other skill levels (Table 5). The risk of concussion in the men’s games decreased across time during the study period. Specifically, the number of concussions caused by illegal hits decreased over time. By contrast, the annual rate of concussions caused by illegal reasons slowly increased among women and juniors. Consequently, the concussion risk was lower in men’s tournaments than in junior tournaments from 2012 until the end of the study period. Gender was a non-significant risk factor for concussions in international games [male-to-female Risk Ratio=1.3 (95% CI = 0.9–1.9)].

<table>
<thead>
<tr>
<th>Gender and Tournament Level</th>
<th>Injury Rate (# / 100 games)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Tournaments</td>
<td>5</td>
</tr>
<tr>
<td>Men’s All</td>
<td></td>
</tr>
<tr>
<td>Senior</td>
<td>5</td>
</tr>
<tr>
<td>Under-20</td>
<td>5</td>
</tr>
<tr>
<td>Under-18</td>
<td>5</td>
</tr>
<tr>
<td>Men’s highest level (A-pool)</td>
<td></td>
</tr>
<tr>
<td>Senior</td>
<td>7</td>
</tr>
<tr>
<td>Under-20</td>
<td>6</td>
</tr>
<tr>
<td>Under-18</td>
<td>7</td>
</tr>
<tr>
<td>Women All</td>
<td></td>
</tr>
<tr>
<td>Highest level (A-pool)</td>
<td></td>
</tr>
<tr>
<td>Girls’ Under-18</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 5. Injury rates for concussion per 100 games in various tournaments.
5.2 Typical features of concussions

Contact with another player was involved in 89% of all (and 91% of men’s A-pool) concussive injuries included in Study I. A check to the head was significantly the most common cause of concussion among male athletes. The majority (56%) of all concussions occurred without board contact. Especially in the Under-20 A-pool tournaments (72%) and the women’s Under-18 (67%) tournaments, concussions occurred in a location away from the boards. However, when concussion was associated with board contact, the risk of injury was significantly lower if the game was played on a rink with flexible boards and glass instead of a rink with traditional materials [for the latter, Risk Ratio=6.4 (95% CI = 1.5–27.6)]. By contrast, the concussion rate was not associated with rink materials when the injury occurred without board contact.

According to Study I, the concussion rate of forwards seemed to be higher than that of defensemen when on-ice proportional representation was considered (usually two wings, one center, two defensemen and a goaltender per team are on ice at the same time). Wings suffered 41% of all concussions in the men’s A-pool tournaments, with centers suffering 26% and defensemen suffering 33%. Centers had a relatively high risk for concussion in the women’s tournaments as well. The goaltenders were at a much lower risk of concussion than other players in all tournaments (1% of all concussions). When the rink position during the injurious event was considered, 21% of all concussions occurred between the blue lines (the neutral zone). Moreover, relatively even distributions of concussions were located in the home zone (36%) and the visitor zone (37%). The rink location distribution for concussions in men’s A-pool tournaments was as follows: home zone 41%, visitor zone 35%, and neutral zone 23%. Regarding the timing of concussive events, most concussions at the men’s highest level of competition occurred during the first period (43%). The finding differs from the risk analysis in the women’s and junior Under-18 tournaments, where the risk for concussion was highest in the third period and the least in the first period.

In Study I, we also observed an impressive behavior change. Following the 4th Consensus Statement on Concussion in Sport (published in 2013), which recommends that athletes do not return to play on the day of injury, none of the concussed players participating in the men’s tournaments continued to play in the same game. However, the policy of returning to competition on the day of injury has not changed in other tournaments.
5.3 Sideline evaluation components of the Sport Concussion Assessment Tool

5.3.1 Symptom evaluation

According to the normative values identified throughout our work (Study II), it is uncommon for uninjured athletes to report four or more symptoms at baseline. Furthermore, a total Symptom Severity Score of 6 or greater should be considered uncommon among uninjured athletes. By contrast, all concussed players reported an “uncommon” number and severity of symptoms on the day-of-injury assessment (Study IV). The uncommon worsening of the baseline symptoms in our two-season test-retest sample was +3 or more for the number of symptoms and +5 or more for the total severity (Study III). When the day-of-injury symptoms were compared to each athlete’s latest baseline, 96% of the concussed players had uncommon worsening in both the number and severity of symptoms (Study IV). For a more detailed comparison of the Symptom Scores and Severities between the uninjured and concussed athletes, see Tables 6 and 7.

In Study II, the total number and severity of baseline symptoms had no statistically significant association with age, years of education, history or number of past concussions, history of headache or migraine, or recovery time after the last concussion. However, worse Symptom Scores were related to past hospitalization or neuroimaging following head trauma (M=2.4, SD=4.0 versus M=1.3, SD=2.2; Mann–Whitney U=5256.0, p<0.05, Cohen’s d=0.5). Study III demonstrated that the test-retest difference scores of the two-season baselines had no statistically significant association with examiner (same/different), age (under/over 20 years), history of headache or migraine (yes/no), or self-reported history of concussion between the two baselines (yes/no).
Summary of the results

Table 6. Symptom Score statistics for uninjured and concussed athletes.

<table>
<thead>
<tr>
<th>SYMPTOM SCORE (0-22 points)</th>
<th>Uninjured athletes</th>
<th>Concussed athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive statistics</td>
<td>League normative reference values (n=284)</td>
<td>Day-of-concussion values (n=24)</td>
</tr>
<tr>
<td>Md=1, M=2, SD=3, IQR=0–2, Range=0–21</td>
<td>Md=12, M=12, SD=4, IQR=9–17, Range=5–19</td>
<td></td>
</tr>
<tr>
<td>Test-retest correlations and effect sizes</td>
<td>Two-season test-retest sample (n=170)</td>
<td>Day-of-concussion test retest difference scores</td>
</tr>
<tr>
<td>Spearman’s r=0.41, p&lt;0.05</td>
<td>Day-of-concussion (n=24) vs. league norms (n=266*)</td>
<td>Two-season test-retest sample (n=170)</td>
</tr>
<tr>
<td>Kendall’s tau b=0.36, p&lt;0.05</td>
<td></td>
<td>day-of-concussion scores (n=24)</td>
</tr>
<tr>
<td>Wilcoxon signed-rank test p=0.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of the sample in range</td>
<td>League normative reference values (n=284)</td>
<td>Day-of-concussion values (n=24)</td>
</tr>
<tr>
<td>Above average: 3 or more</td>
<td>20%</td>
<td>100%</td>
</tr>
<tr>
<td>Uncommon: 4 or more</td>
<td>10%</td>
<td>100%</td>
</tr>
<tr>
<td>Extremely high: 11 or more</td>
<td>2%</td>
<td>63%</td>
</tr>
<tr>
<td>Test-retest difference scores</td>
<td>Two-season test-retest sample (n=170)</td>
<td></td>
</tr>
<tr>
<td>Midmost: -3 to +4</td>
<td>90%</td>
<td>4%</td>
</tr>
<tr>
<td>Uncommon: +3 or more</td>
<td>10%</td>
<td>96%</td>
</tr>
<tr>
<td>Extremely uncommon: +5 or more</td>
<td>5%</td>
<td>92%</td>
</tr>
</tbody>
</table>

Note: Md=Median, M=Mean, SD=Standard deviation, IQR=interquartile range. *Baseline tests of the concussed players were removed from the league normative database before conducting the Mann–Whitney U and Cohen’s d analyses.

Table 7. Severity Score statistics for uninjured and concussed athletes.

<table>
<thead>
<tr>
<th>SYMPTOM SEVERITY (0-132 points)</th>
<th>Uninjured athletes</th>
<th>Concussed athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive statistics</td>
<td>League normative reference values (n=284)</td>
<td>Day-of-concussion values (n=24)</td>
</tr>
<tr>
<td>Md=1, M=2, SD=5, IQR=0–3, Range=0–61</td>
<td>Md=23, M=26, SD=13, IQR=15–34, Range=9–52</td>
<td></td>
</tr>
<tr>
<td>Test-retest correlations and effect sizes</td>
<td>Two-season test-retest sample (n=170)</td>
<td>Day-of-concussion test retest difference scores</td>
</tr>
<tr>
<td>Spearman’s r=0.38, p&lt;0.05</td>
<td>Day-of-concussion (n=24) vs. league norms (n=266*)</td>
<td>Two-season test-retest sample (n=170)</td>
</tr>
<tr>
<td>Kendall’s tau b=0.33, p&lt;0.05</td>
<td></td>
<td>day-of-concussion scores (n=24)</td>
</tr>
<tr>
<td>Wilcoxon signed-rank test p=0.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of the sample in range</td>
<td>League normative reference values (n=284)</td>
<td>Day-of-concussion values (n=24)</td>
</tr>
<tr>
<td>Above average: 4 or more</td>
<td>17%</td>
<td>100%</td>
</tr>
<tr>
<td>Uncommon: 6 or more</td>
<td>10%</td>
<td>100%</td>
</tr>
<tr>
<td>Extremely high: 19 or more</td>
<td>2%</td>
<td>58%</td>
</tr>
<tr>
<td>Test-retest difference scores</td>
<td>Two-season test-retest sample (n=170)</td>
<td></td>
</tr>
<tr>
<td>Midmost: -6 to +6</td>
<td>91%</td>
<td>0%</td>
</tr>
<tr>
<td>Uncommon: +5 or more</td>
<td>9%</td>
<td>96%</td>
</tr>
<tr>
<td>Extremely uncommon: +7 or more</td>
<td>4%</td>
<td>96%</td>
</tr>
</tbody>
</table>

Note: Md=Median, M=Mean, SD=Standard deviation, IQR=interquartile range. *Baseline tests of the concussed players were removed from the league normative database before conducting the Mann–Whitney U and Cohen’s d analyses.
Finally, the analysis conducted within Study IV revealed that the number and severity of post-injury symptoms were significantly greater than individual baseline values. Large effect sizes were found when the day-of-injury scores were compared to the uninjured athletes’ values in the normative sample (Cohen’s $d=3.9$) and also when compared to the baseline values of the concussed athletes (Cohen’s $d=2.4$). In addition, excellent classification accuracy for distinguishing between concussed and uninjured athletes was found when the AUC and 95% confidence intervals (CI) were calculated. The AUC was 0.98 (95% CI = 0.96–0.99) for the Symptom Score and 0.98 (95% CI = 0.97–1.00) for the Symptom Severity Score. Similarly, baseline-adjusted post-injury scores showed a great ability to discriminate between concussed and uninjured players for the Symptom Score (AUC=0.95, 95% CI = 0.88–1.00) and Symptom Severity Score (AUC=0.95, 95% CI = 0.88–1.00). See Figures 5 and 6.

![Symptom Score](image)

Note: The black line represents the proportions of post-injury scores ($n=24$). The gray line represents the proportions of the 2013–14 preseason baseline scores among uninjured players ($n=266$). The vertical line is the cutoff point for the uncommon values.

**Figure 5.** The frequency distributions of endorsed symptoms in concussed and uninjured players.
Summary of the results

Note: The black line represents the proportions of post-injury scores (n=24). The gray line represents the proportions of the 2013–14 preseason baseline scores among uninjured players (n=266). The vertical line is the cutoff point for the uncommon values.

**Figure 6.** The frequency distributions of Symptom Severities in concussed and uninjured players.

More than half of the athletes (52%) reported at least one symptom during the baseline evaluation. The most commonly endorsed baseline symptoms were neck pain (24%), fatigue or low energy (22%), trouble falling asleep (16%), and drowsiness (15%) (Study II). The most commonly endorsed post-injury symptoms were “Don’t feel right” (100%), Headache (96%), and “Pressure in head” (92%). In addition, these symptoms were the most common to worsen compared to the individual baseline symptom ratings (Study IV). Figure 7 provides the day-of-injury and baseline scores for each symptom.

Figure 8 illustrates the post-injury-to-baseline change of each symptom’s severity. For comparison, the two-season baseline-to-baseline difference of concussed players and league normatives are also shown in Figure 8.
Summary of the results

The Sport Concussion Assessment Tool in the Management of Concussion in Professional Ice Hockey

Note: The uppermost bars present the severities of the day-of-injury symptoms (n=24). The bars in the middle present the severities of the baseline symptoms among the concussed players (n=24), and the bar at the bottom presents the severities of the baseline symptoms reported by the league’s normative sample (n=284).

**Figure 7.** The rates (% of the sample) of each symptom’s severity.
Summary of the results

Note: The first bars present the post-injury-to-personal baseline change in Symptom Severity Score among concussed athletes (n=24). The second bars present the two-season test-retest change in baseline Symptom Severity Score among concussed athletes (n=19–20). The third bars present the two-season test-retest change in baseline Symptom Severity Score among the normative sample (n=171).

Figure 8. Test-retest change of each symptom’s severity.

5.3.2 Standardized Assessment of Concussion (SAC)

The normative values (Study II) show that scoring 24 or fewer total points in the SAC is uncommon for uninjured athletes during the baseline examination. Furthermore, our two-season test-retest sample (Study III) demonstrated that a SAC total score that is 3 or more points worse than the previous baseline should be considered uncommon. Finally, when the day-of-injury SAC total performance was compared to personal baselines, 33% of the concussed athletes had an uncommon worsening of the score. Similarly, if normative value-based classification ranges were used, 27% of the injured athletes were classified with uncommon performance (Study IV). A more detailed comparison between uninjured and concussed athletes’ SAC scores is presented in Table 8.
Summary of the results

The Sport Concussion Assessment Tool in the Management of Concussion in Professional Ice Hockey

SAC (0-30 points) | Uninjured athletes | Concussed athletes
--- | --- | ---
**Descriptive statistics** | League normative reference values (n=279) | Day-of-concussion values (n=22)
**Test-retest correlations and effect sizes** | Two-season test-retest sample (n=169) | Day-of-concussion (n=22) vs. league norms (n=260*)
| Spearman’s r=0.34, p<0.05 | Mann–Whitney U test: p<0.05
Kendall’s tau b=0.27, p<0.05 | Cohen’s d=0.9
Wilcoxon signed-rank test p=0.05

% of the sample in range
- Below average: 25 or less
- Uncommon: 24 or less
- Extremely low: 23 or less

| League normative reference values (n=279) | Day-of-concussion values (n=22) |
| 17% | 41% |
| 9% | 27% |
| 2% | 27% |

Test-retest difference scores | Two-season test-retest sample (n=169) | Baseline-adjusted day-of-concussion scores (n=21)
- Midmost: -3 to +4
- Uncommon: -3 or more
- Extremely uncommon: -4 or more

| 95% | 76% |
| 7% | 34% |
| 2% | 24% |

Note: Md=Median, M=Mean, SD=Standard deviation, IQR=interquartile range. *Baseline tests of the concussed players were removed from the league normative database before conducting the Mann–Whitney U and Cohen’s d analyses.

Table 8. SAC Total statistics for uninjured and concussed athletes.

The SAC total baseline score had no statistically significant association with age, years of education, history of headache or migraine, number or history of past concussions, history of hospitalization or neuroimaging following head trauma, or recovery time after the previous concussion (Study II). In addition, Study III demonstrated that the test-retest difference scores of the SAC had no statistically significant association with examiner (same/different), age (under/over 20 years), history of headache or migraine (yes/no), or self-reported history of concussion between baselines (yes/no).

Study IV revealed that the post-injury SAC total score was significantly lower on the day of injury relative to both the baseline values of uninjured athletes in the normative sample (Cohen’s d=0.88) and the baseline values of the concussed players (Cohen’s d=0.68). However, the ability to discriminate between concussed and uninjured athletes was poor not only for the SAC total scores (AUC=0.64 CI=0.50–0.79), but also for the baseline-adjusted change scores of the SAC total (AUC=0.71, CI=0.59–0.83). See Figure 9.
Descriptive statistics for each subtest of the SAC are presented in Table 9. No significant day-of-injury deficits were observed for any of the subtests when post-injury scores were compared to the baselines of the concussed players (Wilcoxon-signed ranks test: $p>0.05$). Orientation was the only subtest with a significantly lower day-of-injury score when compared to the baselines of uninjured athletes in the normative sample (Mann–Whitney U: $p<0.05$, Cohen’s $d=0.8$).

Few clinically interesting features of the SAC subtests emerged among concussed athletes. First, it appears that any error in the orientation test might be associated with injury. Second, the immediate memory test seems to be unreliable in distinguishing between concussed and uninjured athletes. Third, a perfect performance in the concentration test does not mean that an injury has not occurred. Last, a change in delayed recall score is not a reliable indicator of a concussion, but scoring zero is highly suspicious for injury. For more detailed arguments for our observations, see Study IV.
### Table 9. SAC subcomponent statistics for uninjured and concussed athletes.

<table>
<thead>
<tr>
<th>SUBCOMPONENT</th>
<th>Descriptive statistics</th>
<th>Uncommon performance</th>
<th>Extremely low score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orientation</strong></td>
<td>(R=0-5 points)</td>
<td>(4 or less)</td>
<td>(3 or less)</td>
</tr>
<tr>
<td>Uninjured athletes</td>
<td>Md=5, M=5, SD=0, R=3-5</td>
<td>8%</td>
<td>1%</td>
</tr>
<tr>
<td>Concussed athletes</td>
<td>Md=5, M=5, SD=1, R=2-5</td>
<td>29%</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Immediate memory</strong></td>
<td>(R=0-15 points)</td>
<td>(13 or less)</td>
<td>(12 or less)</td>
</tr>
<tr>
<td>Uninjured athletes</td>
<td>Md=15, M=15, SD=1, R=12-15</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>Concussed athletes</td>
<td>Md=15, M=14, SD=1, R=11-15</td>
<td>17%</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Concentration</strong></td>
<td>(R=0-5 points)</td>
<td>(2 or less)</td>
<td>(1 or less)</td>
</tr>
<tr>
<td>Uninjured athletes</td>
<td>Md=4, M=4, SD=1, R=2-5</td>
<td>4%</td>
<td>0%</td>
</tr>
<tr>
<td>Concussed athletes</td>
<td>Md=4, M=4, SD=1, R=2-5</td>
<td>9%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Delayed recall</strong></td>
<td>(R=0-5 points)</td>
<td>(1 or less)</td>
<td>(0)</td>
</tr>
<tr>
<td>Uninjured athletes</td>
<td>Md=4, M=4, SD=1, R=0-5</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>Concussed athletes</td>
<td>Md=3, M=4, SD=2, R=0-5</td>
<td>17%</td>
<td>13%</td>
</tr>
</tbody>
</table>

Note: “Uninjured athletes” refers to normative sample in Study II (n=282–285), “Concussed athletes” refers to the day-of-concussion values in Study IV (n=23–24). Md=Median, M=Mean, SD=Standard deviation, R=Range.

#### 5.3.3 Modified Balance Error Scoring System (M-BESS)

According to normative values (Study II), it is uncommon for uninjured athletes to score six or more M-BESS errors at baseline. In addition, a worsening by three or more errors in the latter baseline was uncommon in our two-season test-retest sample (Study III). The percentage of players with uncommon day-of-injury M-BESS performance was 46%, despite the interpretation method used (Study IV). For more a detailed comparison of the M-BESS scores between the uninjured and concussed athletes, see Table 10.

The baseline performance in M-BESS had no statistically significant association with age, years of education, history of headache or migraine, history or number of past concussions, history of hospitalization or neuroimaging following head trauma, or recovery time after the last concussion (Study II). Moreover, the test-retest difference scores of the M-BESS had no statistically significant association with examiner (same/different), age (under/over 20 years), history of headache or migraine (yes/no), or self-reported history of concussion (yes/no) between baselines (Study III).
Summary of the results

<table>
<thead>
<tr>
<th>M-BESS (0-30 errors)</th>
<th>Uninjured athletes</th>
<th>Concussed athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive statistics</td>
<td>League normative reference values (n=295)</td>
<td>Day-of-concussion values (n=26)</td>
</tr>
<tr>
<td>Md=1, M=2, SD=3, IQR=0-2, Range=0-20</td>
<td>Md=5, M=7, SD=7, IQR=1-10, Range=0-30</td>
<td></td>
</tr>
<tr>
<td>Test-retest correlations and effect sizes</td>
<td>Two-season test-retest sample (n=176)</td>
<td>Day-of-concussion (n=26) vs. league norms (n=273*)</td>
</tr>
<tr>
<td>Spearman’s r=0.25, p&lt;0.05</td>
<td>Mann–Whitney U test: p&lt;0.05</td>
<td></td>
</tr>
<tr>
<td>Kendall’s tau b=0.21, p&lt;0.05</td>
<td>Cohen’s d=1.5</td>
<td></td>
</tr>
<tr>
<td>Wilcoxon signed-rank test p&lt;0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of the sample in range</td>
<td>League normative reference values (n=295)</td>
<td>Day-of-concussion values (n=26)</td>
</tr>
<tr>
<td>Above average: 4 or more</td>
<td>17%</td>
<td>54%</td>
</tr>
<tr>
<td>Uncommon: 6 or more</td>
<td>6%</td>
<td>46%</td>
</tr>
<tr>
<td>Extremely high: 11 or more</td>
<td>2%</td>
<td>19%</td>
</tr>
<tr>
<td>Test-retest difference scores</td>
<td>Two-season test-retest sample (n=176)</td>
<td>Baseline-adjusted day-of-concussion scores (n=26)</td>
</tr>
<tr>
<td>Midmost: -4 to +4</td>
<td>90%</td>
<td>58%</td>
</tr>
<tr>
<td>Uncommon: +3 or more</td>
<td>9%</td>
<td>46%</td>
</tr>
<tr>
<td>Extremely uncommon: +5 or more</td>
<td>5%</td>
<td>42%</td>
</tr>
</tbody>
</table>

Note: Md=Median, M=Mean, SD=Standard deviation, IQR=interquartile range. *Baseline tests of the concussed players were removed from the league normative database before conducting the Mann–Whitney U and Cohen’s d analyses.

Table 10. M-BESS statistics for uninjured and concussed athletes.

![M-BESS](image)

Note: The black line represents the proportions of post-injury errors (n=26). The gray line represents the proportions of the 2013–14 preseason baseline errors among uninjured players (n=273). The vertical line is the cutoff point for the uncommon values.

Figure 10. The frequency distributions of M-BESS errors in concussed and uninjured players.

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The number of M-BESS errors committed by injured athletes was significantly higher than the baseline values of the uninjured athletes in the normative sample (Cohen’s d=1.46) and the baseline scores of the concussed athletes (Cohen’s d=1.06). Nevertheless, the ability to discriminate between uninjured and concussed athletes was poor. In Study IV, the AUC for the post-injury M-BESS score was 0.69 (CI=0.56–0.82) and the AUC for the baseline-adjusted post-injury score was 0.72 (CI=0.60–0.84). See Figure 10.

Over the two-season baseline testing, all athletes had perfect performance in the double-leg stance M-BESS subtest (Studies II and III), but two concussed athletes scored at least one post-injury error (Study IV). Descriptive statistics for the single-stance and tandem stance are presented in Table 11. The number of post-injury errors committed in the tandem stance was significantly higher than the baseline values of the uninjured athletes in the normative sample (Mann–Whitney U: p<0.05, Cohen’s d=1.2) and the baseline scores of the concussed athletes (Wilcoxon-signed rank test: p<0.05, Cohen’s d=0.9). The number of day-of-injury single-leg stance errors was significantly higher than the baseline values (both p<0.05, Cohen’s d=1.0).

<table>
<thead>
<tr>
<th>SUBCOMPONENT</th>
<th>Descriptive statistics</th>
<th>Uncommon performance % of the sample in range</th>
<th>Extremely high score % of the sample in range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single leg stance</td>
<td>(R=0–10 errors)</td>
<td>(4 or more)</td>
<td>N/A</td>
</tr>
<tr>
<td>Uninjured athletes</td>
<td>Md=1, M=1, SD=2, R=0–10</td>
<td>9%</td>
<td>N/A</td>
</tr>
<tr>
<td>Concussed athletes</td>
<td>Md=2, M=3, SD=4, R=0–10</td>
<td>38%</td>
<td>N/A</td>
</tr>
<tr>
<td>Tandem stance</td>
<td>(R=0–10 errors)</td>
<td>(2 or more)</td>
<td>(5 or more)</td>
</tr>
<tr>
<td>Uninjured athletes</td>
<td>Md=0, M=1, SD=2, R=0–10</td>
<td>9%</td>
<td>2%</td>
</tr>
<tr>
<td>Concussed athletes</td>
<td>Md=1, M=3, SD=4, R=0–10</td>
<td>46%</td>
<td>19%</td>
</tr>
</tbody>
</table>

Note: “Uninjured athletes” refers to the normative sample in Study II (n=296-301), “Concussed athletes” refers to the day-of-concussion values in Study IV (n=26). Md=Median, M=Mean, SD=Standard deviation, R=Range.

Table 11. M-BESS subcomponent statistics for uninjured and concussed athletes.

If we consider the M-BESS subtests individually, different clinical aspects emerged (Study IV). For the single-leg stance subtest, our observations suggest that a range of 0–3 errors is not reflective of the presence of a concussion, but scoring more than three errors indicates an injury. All of the concussed athletes had fewer than four baseline errors, but only 26% scored a perfect baseline performance. By contrast, more than one-third scored more than four post-injury errors. For the tandem stance subtest, scoring more than four errors is highly suspicious for injury.
None of the concussed athletes demonstrated more than four baseline errors in this subtest, but 5 of 26 scored the maximum 10/10 post-injury errors.

5.3.4 Tandem Gait (TG)

According to our normative values, there was widespread variability (range=6.7–14.3 seconds) in the TG baseline times among uninjured athletes. The cutoff for uncommon performance was adjusted to 12.9 seconds. Only one participant in the normative sample could not perform the baseline test in 14 seconds, as suggested by the SCAT3 (Study II). An increase by 4 or more seconds from the previous baseline time was uncommon in our two-season test-retest sample (Study III). Of the concussed players, 18% had uncommon worsening of TG time when the day-of-injury performance was compared to the personal baseline. Furthermore, 31% of the post-injury times were slower than the cutoff for uncommon performance (Study IV). For a more detailed comparison of the TG scores between uninjured and concussed athletes, see Table 12.

The baseline TG time was not significantly associated with age, years of education, history or number of past concussions, history of headache or migraine, or recovery time after the last concussion. Better TG performance was marginally related to past hospitalization or neuroimaging following head trauma (M=9.9, SD=2.0 versus M=11.0, SD=1.6; Mann–Whitney U=486.0, p<0.05; Cohen’s d=0.6) in Study II. The test-retest difference in TG time was not significantly related to the examiner (same/different), age (under/over 20 years), history of headache or migraine (yes/no), or self-reported history of concussion between baselines (yes/no) in Study III.

Moreover, no significant day-of-injury deficits were observed for the TG using either the uninjured athletes in the normative sample (p=0.5) or the baseline times of the concussed athletes (p=0.5) for comparison. In addition, the ability to discriminate between concussed and uninjured athletes was poor. The AUC for absolute TG time was 0.56 (CI=0.35–0.78), while the AUC for the baseline-adjusted time was 0.55 (CI=0.32–0.78) in Study IV (Figure 11).
## Summary of the results

### TANDEM GAIT (seconds)

<table>
<thead>
<tr>
<th>Test-retest correlations and effect sizes</th>
<th>Uninjured athletes</th>
<th>Concussed athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td>League normative reference values (n=94)</td>
<td>Md=10.9, M=10.8, SD=1.8, IQR=9.6−12.1, R=6.7−14.3</td>
<td>Day-of-concussion values (n=13)</td>
</tr>
<tr>
<td>Two-season test-retest sample (n=44)</td>
<td>Spearman’s r=0.04, p=0.78</td>
<td>Day-of-concussion (n=13) vs. league norms (n=91*)</td>
</tr>
<tr>
<td>Kendall’s tau b=0.03, p=0.81</td>
<td>Wilcoxon signed-rank test p=0.96</td>
<td>Cohen’s d=0.2</td>
</tr>
</tbody>
</table>

### % of the sample in range

| Below average: 12.2 or slower | 23% | 54% |
| Uncommon: 12.9 or slower | 10% | 31% |
| Extremely slow: 14.0 or slower | 1% | 8% |

### Test-retest difference scores

| Two-season test-retest sample (n=44) | Baseline-adjusted day-of-concussion scores (n=11) |
| Midmost: -3 to +3 | 89% | 73% |
| Uncommon: +4 or more | 7% | 18% |

Note: Md=Median, M=Mean, SD=Standard deviation, IQR=interquartile range, R=Range. *Baseline tests of the concussed players were removed from the league normative database before conducting the Mann-Whitney U and Cohen’s d analyses.

**Table 12.** Tandem Gait statistics for uninjured and concussed athletes.

![Tandem Gait statistics graph]

Note: The black line represents the proportions of post-injury times (n=13). The gray line represents the proportions of the 2013–14 preseason baseline times among uninjured players (n=91). The vertical line is the cutoff point for the uncommon values.

**Figure 11.** The frequency distributions of Tandem Gait times in concussed and uninjured players.
5.3.5 Finger-to-nose (FTN) coordination task

Three athletes (1%) in our normative sample (n=285) failed the baseline FTN task (Study II) and none of these athletes failed the second baseline in our two-season test-retest study (Study III). Moreover, only two concussed athletes performed poorly in the post-injury test and both of these athletes had perfect baseline performance (Study IV). No detailed statistical analyses could be performed due to the small subgroup frequencies.

5.4 Post-injury SCAT interpretation methods and component combinations

Above all, the post-injury impairment identification slightly improved if the two interpretation methods for post-injury performance (i.e., comparison to normative reference values and comparison to personal baseline) were used simultaneously. The classification accuracy of SCAT3 components to distinguish between concussed and uninjured athletes was not dependent on the score used (i.e., absolute score or baseline-adjusted change score) in the receiver operating characteristics curve analysis. Table 13 demonstrates the percentages of the athletes with uncommon post-injury performance when a component or different combinations of components were used for the classification.

In general, the test-retest reliabilities of the SCAT3 components were uniformly low, although most of the mean baseline scores seemed to remain stable and a large majority of the athletes scored each component either in the same or a higher normative performance range in the second baseline (Study III). The only statistically significant correlation between the SCAT3 components in baselines (Study II) was between the SAC and the Tandem Gait (r=-0.25, p<0.05) tests, illustrating a marginal but unlikely clinically relevant association between these measures. Furthermore, the Spearman’s correlation between the M-BESS performance and Tandem Gait time was not significant (r= -0.06, p=0.6).
### Summary of the results

The Sport Concussion Assessment Tool in the Management of Concussion in Professional Ice Hockey

<table>
<thead>
<tr>
<th>SCAT3 components and their combinations</th>
<th>Uncommon Post-Injury Score</th>
<th>Uncommon Baseline-Adjusted Post-Injury Score</th>
<th>Uncommon Post-Injury Score or/and Baseline-Adjusted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptom Score</td>
<td>(n=23, n=23)</td>
<td>100%</td>
<td>96%</td>
</tr>
<tr>
<td>Symptom Severity</td>
<td>(n=23, n=23)</td>
<td>100%</td>
<td>96%</td>
</tr>
<tr>
<td>SAC</td>
<td>(n=22, n=21)</td>
<td>27%</td>
<td>33%</td>
</tr>
<tr>
<td>M-BESS</td>
<td>(n=26, n=26)</td>
<td>46%</td>
<td>46%</td>
</tr>
<tr>
<td>Tandem Gait</td>
<td>(n=13, n=11)</td>
<td>31%</td>
<td>18%</td>
</tr>
<tr>
<td>SAC, M-BESS</td>
<td>(n=22, n=21)</td>
<td>64%</td>
<td>76%</td>
</tr>
<tr>
<td>SAC, Tandem Gait</td>
<td>(n=11, n=10)</td>
<td>45%</td>
<td>40%</td>
</tr>
<tr>
<td>M-BESS, Tandem Gait</td>
<td>(n=13, n=11)</td>
<td>77%</td>
<td>82%</td>
</tr>
<tr>
<td>SAC, M-BESS, Tandem Gait</td>
<td>(n=11, n=10)</td>
<td>82%</td>
<td>90%</td>
</tr>
<tr>
<td>Symptom Score, Symptom Severity</td>
<td>(n=23, n=23)</td>
<td>100%</td>
<td>96%</td>
</tr>
<tr>
<td>Symptoms*, SAC, M-BESS, Tandem Gait</td>
<td>(n=10, n=9)</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Note: Post-injury score was considered uncommon if the player scored within the worst 10th percentile of the normative reference values (Study II) in any of the components mentioned in the first column. The test-retest difference score corresponding to the cutoff for the worst 10th percentile ranks in our two-season baseline study (Study III) was used to classify if the baseline-adjusted post-injury score was uncommon or not. * “Symptoms” means that both Symptom Score and Symptom Severity were used.

**Table 13.** The percentage (%) of concussed athletes considered performing uncommonly when different combinations of SCAT3 components were used for assessment.
6 DISCUSSION

6.1 The incidence of ice hockey-related concussion

The incidence (7 per 100 games) of sport-related concussion among professional male ice hockey players in our sample was consistent with data obtained from the NHL (Hutchison et al. 2015a, Kerr et al. 2016, Echemendia et al. 2017a). It has been suggested that the rate of concussion might be higher among female players than male players (Schick, Meeuwisse 2003, Hootman, Dick & Agel 2007). Even so, gender was a non-significant risk factor in the current study. In reviewing the literature of junior (collegiate and high school) ice hockey players, similar (Marar et al. 2012) or slightly higher (Agel, Harvey 2010) injury rates were found compared to this study.

One interesting finding in Study I was the risk of concussion in the men’s games decreasing during the study period; since 2012, the risk has been lower during men’s tournaments compared to juniors’ tournaments. In particular, the number of concussions caused by illegal hits decreased in the men’s tournaments. At the same time, the annual rate of illegally caused concussions slowly increased among women and juniors. Thus, more focus on illegal hits causing concussions is needed, particularly in women’s and junior ice hockey.

Modern rink materials and protective installation methods have been produced to improve impact energy resorption, resulting in lower peak forces and greater stopping distances (Barth et al. 2001, Poutiainen et al. 2014). However, Study I was the first to report that the risk of concussion associated with board contact was significantly lower if the game was played on a rink with flexible boards and glass instead of a rink with traditional materials.
6.2 Characteristics of ice hockey-related concussions in professional male athletes

The current findings (Study I) of typical ice hockey-related concussion characteristics among professional male athletes are consistent with data obtained from the NHL (Benson et al. 2011, Hutchison 2011, Izraelski 2013, Hutchison et al. 2015a, Hutchison et al. 2015b, Echemendia et al. 2017a). Accordingly, player-to-player contact in which a taller and heavier opponent uses his shoulder to impact the lateral aspect of the injured player’s head was the typical mechanism for concussion. Relatively even distributions of concussions occurred with and without board contact. In addition, the majority of the concussive events took place in the first period, when the players were likely more energized and able to apply more force with greater acceleration during collisions. Furthermore, goaltenders were at a much lower risk for concussion than other players, and the injury risk for forwards—especially centers—seemed to be higher than for defensemen.

6.3 Combining the findings and previous literature to improve post-injury SCAT interpretation

This study confirms a notable variability between the athletes in SCAT baseline performance. Despite the findings that group-level statistics—as mean and median scores—remained stable from test to retest across the SCAT3 components, the two-season test-retest reliabilities of each component were uniformly low and mostly considered weak according to conventional standards for interpreting the stability of human performance tests. The low correlations are related, in part, to the skewed distributions of the test scores. The limited number of scoring options results in a ceiling effect, where a large number of the values usually accumulate to the minimum and/or maximum score, causing substantial bias to reliability estimations and reducing the magnitude of observed correlations. On the other hand, the scale of the current statistical tests is sometimes too sensitive to analyze the variability of the tools that are useful in clinical practice.

The current findings indicate that new interpretation methods with more validity are needed for clinical decision-making. The problems with reliability may be partially mitigated when post-injury performance is classified using normative
reference ranges, as athletes are classified within a range rather than on a continuous scale. In Study III, most athletes (86–96%) had baseline scores within the same or better normative classification range across a one-year test-retest interval. By contrast, the percentages of the concussed athletes with an uncommon day-of-injury score (classified using the cutoffs for the worst 10th percentile ranks of normative reference values) were as follows: Symptoms 100%, M-BESS 46%, Tandem Gait 31%, and SAC 27%. Additionally, the interpretation of baseline-adjusted post-injury scores improves if the change in performance is classified considering the natural distribution of test-retest difference scores in uninjured athletes. An uncommon test-retest difference score occurred in fewer than 10% of the uninjured athletes, but the percentages of the concussed players with uncommon baseline-adjusted post-injury scores were as follows: Symptoms 96%, M-BESS 46%, SAC 33%, and Tandem Gait 18%.

There is no evidence-based guideline regarding whether or not SCAT baseline testing is necessary, or how often to do baseline testing (e.g., annually or less frequently). In this study, league normative reference values had a similar degree of sensitivity to acute concussion effects compared to individual baseline scores. The current findings are consistent with previous studies (Putukian et al. 2015, Chin et al. 2016), illustrating that SCAT administration does not achieve statistically significant added value when using the individual baseline as a comparator for post-injury performance compared to normative data. Furthermore, baseline testing often requires significant time, financial, and personnel investments. Thus, normative ranges offer an alternative with high clinical feasibility when available. However, caution is warranted when relying on normative data comparisons, as interpretation should consider age, sex, and perhaps sport as modifying factors, which are not available for all post-injury tests or across all populations who may sustain a concussion. Clinicians should also be aware of the limitations of normative ranges. For example, in Study IV, some athletes with a substantial post-injury-to-baseline score decline still had an absolute post-injury score that was considered “broadly normal” if normative ranges were used. Conversely, the baseline-adjusted score – i.e., post-injury-to-baseline change score – may also be misleading. For example, the only concussed player (in study IV) having an extremely unusual Symptom Score and Symptom Severity Score already during the baseline assessments was also the only athlete whose baseline-adjusted post-injury Symptom and Severity Scores were not classified as uncommon. Thus, considering the normative ranges alongside the athlete’s baseline scores helps the clinician to identify individuals whose baseline-adjusted post-injury scores require extra caution when being interpreted.
Discussion

In conclusion, it is reasonable to assume that the best way to interpret SCAT scores is a combination of the two methods: (i) classifying post-injury scores by normative reference ranges that are based on an appropriate population; and (ii) comparing the athlete’s post-injury score to the personal baseline score while considering the natural variation of test-retest difference scores. In addition, more research is needed to determine the optimal frequency of baseline testing with the SCAT, such as studies comparing reliability over different time periods and studies comparing post-injury scores to baseline scores after varying time intervals.

6.3.1 Symptom evaluation

The present study confirms the previous findings (Broglio, Puetz 2008, Schmidt et al. 2012, Putukian et al. 2015, Chin et al. 2016, McCrory et al. 2017b) and contributes additional evidence suggesting that the symptom inventory is the most sensitive SCAT component to discriminate between concussed and uninjured athletes. Based on the current results and previous studies (Jinguji et al. 2012, Putukian et al. 2015, Zimmer et al. 2015, Chin et al. 2016), the lowest Symptom Score that should be considered uncommon is between 4 and 8, depending on the reference. Furthermore, a baseline-adjusted Symptom Score of 3 or more should be considered uncommon. Similarly, the cutoff score for an uncommon Symptom Severity Score ranges between 6 and 10. Worsening of the Symptom Severity Score by 5 or more points should be considered uncommon.

The reported number and severity of symptoms listed on the SCAT may be a sensitive way to classify concussed patients from uninjured ones on the day of suspected injury. However, the symptoms are not specific to concussion and may occur as a result of other clinical conditions (Meares et al. 2011), or they may be modulated by factors such as exercise (Gaetz, Iverson 2009). Furthermore, they are reliant on the self-report of the patient, and athletes in particular may under-report their symptoms (McCrea et al. 2004, Meehan et al. 2013). For instance, post-injury Symptom and Severity Scores similar to concussed athletes appeared among players with facial contusions (Study IV).

The findings in Study II are in accord with recent literature (Valovich McLeod et al. 2012, Harmon et al. 2013, Zimmer et al. 2015), indicating that more than half of the uninjured athletes report at least one concussion symptom during the baseline evaluation. Study II also confirmed previous findings (Shehata et al. 2009, Schneider et al. 2010, Zimmer et al. 2015) that the most common baseline symptoms are fatigue.
or low energy, drowsiness, and neck pain. In particular, neck pain was the most common baseline symptom among our adult cohort, whereas fatigue or low energy was the most prominent symptom reported by young athletes. Furthermore, headache was a common baseline symptom, especially among athletes with a history of concussion (Schneider et al. 2010, Zimmer et al. 2015). Study III demonstrated that “fatigue or low energy” and “neck pain” were the symptoms most likely to change between two consecutive baselines. Accordingly, the presence of these symptoms after a suspected concussion should be interpreted with caution and compared to individual baselines where available. The most prevalent day-of-injury symptoms (Study IV) were: “Don’t feel right,” “headache,” and “pressure in the head”. The presence of these symptoms accompanying a suspected concussion warrants caution. Finally, this study suggests that an athlete reporting symptoms such as “feeling like in a fog,” “dizziness,” and/or “confusion” should be considered injured whether the baseline values are available or not. Prior work (Krol et al. 2011, Jinguji et al. 2012) also supports this idea with similar findings of these symptoms being quite commonly reported in the day-of-injury assessment, but very rarely during baselines.

6.3.2 Standardized Assessment of Concussion (SAC)

The ability to discriminate between concussed and non-concussed players when using the day-of-injury SAC total score is very limited (Study IV). This finding supports the recent consensus (Echemendia et al. 2017b) for modifying the cognitive screening of the SCAT to reduce potential ceiling effects, learning effects, and settings-related bias. Based on current results and previous studies (Jinguji et al. 2012, Valovich McLeod et al. 2012, McCrea et al. 2013), a post-injury SAC score of 24 points or lower and/or a worsening of three or more points from the personal baseline should be considered uncommon if the SAC version with the list of five words in immediate memory and delayed recall is used.

6.3.3 Modified Balance Error Scoring System (M-BESS)

Significant differences between baseline and day-of-injury M-BESS performance was demonstrated in Study IV. These findings are consistent with the data obtained from college and high school athletes (Putukian et al. 2015, Chin et al. 2016). Based on our observations and the existing literature on professional ice hockey players
Discussion

(Riemann, Guskiewicz 2000) and young adult athletes (Jinguji et al. 2012, Chin et al. 2016), post-injury M-BESS errors of six or more and/or an increase of three or more errors from personal baseline should be considered uncommon. Additionally, any error in the double-leg stance, more than three errors in single-leg stance, or more than four errors in the tandem stance should be considered to indicate an injury (Studies II–IV, Riemann, Guskiewicz 2000).

6.3.4 Tandem Gait (TG) and Coordination

The ability to discriminate between concussed and uninjured athletes using TG time was poor in Study IV. Furthermore, the wide range of baseline times (Study II) indicates that classification based on normative ranges might not be a reliable method for individual post-injury performance evaluation. These findings support the recent consensus (Echemendia et al. 2017b) for modifying the Tandem Gait test rating for the SCAT5. The present dissertation demonstrated that the specified time to complete the tandem gait task without any error and the M-BESS scores were not related to each other. Thus, these two tests appear to measure different aspects of balance control and may be best used in conjunction. Furthermore, the sensitivity of the SCAT to the effects of concussion may be decreased by the simplified rating of the TG test. For example, in Study IV, three additional athletes were classified with uncommon post-injury balance performance when the interpretation of TG time was combined with the athletes’ M-BESS results, given that one or the other may detect post-injury deficits. Consequently, the percentage of concussed athletes identified with uncommon performance improved from 50% to 91% if the combination of M-BESS and TG was used instead of the M-BESS results alone (Note: concurrently, the sample size halved because of missing post-injury TG values).

Finally, the TG task is not only a balance test but also measurement of lower limb coordination, while upper-limb coordination is assessed using the dichotomously scored finger-to-nose task. Failing in the test is very rare among professional ice hockey players (Studies II–IV) and other athletes (Jinguji et al. 2012, Valovich McLeod et al. 2012). However, future research will show if these two very simplified coordination tests included in the SCAT5 are sufficiently valid for clinical use.
6.4 Reaching the clinical diagnosis of concussion

Without exception, the acute management of head-injured athletes is initiated with a first-line consideration of the need for emergency interventions and the exclusion of life-threatening conditions (e.g., airway problems). Secondly, safe transportation off the field must be secured. If it is obvious through initial screening through visible signs (Echemendia et al. 2017a), injury mechanism (Bruce et al. 2017), and on-field assessments (McCrory et al. 2017b) that an athlete has sustained a concussion or more severe traumatic brain injury, a more detailed neurocognitive assessment in the sideline setting is not necessary for diagnostics. However, acute post-injury use of the SCAT on the sideline serves as a useful reference as the athlete is monitored during the subsequent hours, days, and weeks after injury. Moreover, future research might find correlations to predict more accurate return-to-play times and more individualized management protocols based on the acute post-injury SCAT results.

When an athlete with a suspected concussion is removed from play, an acute sideline SCAT assessment is an essential part of the concussion diagnostics. Considering the fact that the diagnostic utility of the SCAT and its components decrease significantly as time elapses after injury (McCrea et al. 2013, Chin et al. 2016), the tool should be used cautiously after the day of injury. Self-reported day-of-injury symptoms appear to be the most sensitive SCAT component to classify the concussed athletes from the uninjured athletes (Broglio, Puetz 2008, Schmidt et al. 2012, Putukian et al. 2015, Chin et al. 2016, McCrory et al. 2017b). Even so, reliance on symptoms alone is not recommended due to the lack of specificity (Gaetz, Iverson 2009, Meares et al. 2011) and objectivity (Meier et al. 2015, Smith et al. 2017). Similarly, it is important for clinicians to note that variability in performance-based measures (i.e., SAC, M-BESS, and Tandem Gait) is common among uninjured athletes and those with injuries other than concussion (Study IV). Published normative values and individual baselines are helpful in clinical decision-making. Still, there is no consensus on the rules for interpreting post-injury SCAT performance. Finally, the SCAT is not a stand-alone tool for diagnosing concussion. It is rather an adjunct tool that must be used in the hands of medical professionals with proper clinical knowledge and judgement. Concussion is a clinical diagnosis and the SCAT cannot be relied on alone.
6.5  Strengths and limitations

The first part of this dissertation, which investigated the incidence and typical injury characteristics of concussions in ice hockey, included a large number of international male and female players competing at various age and skill levels over a nine-season observation period. This allowed us to follow up the time- and sample-related trends of injury rates and the typical characteristics of concussive events. Despite the reliable data collection instruments used for the systematic registration of all concussions, a more accurate description of the injury mechanism and location on the ice could have been achieved if a detailed review of the multi-angle game videos was used instead of an injury reporting system that relied on the individual team physician’s observations. The advantages of video reviews for injury identification have recently been noted in the updated Consensus Statement on Concussion in Sport (McCrory et al. 2017b, Patricios et al. 2017). In addition, more individualized risk estimations could have been obtained if the precise on-ice exposures of each athlete were measured. Thus, the penalties, overtimes, and time-loss injuries during a game could have been taken into consideration. Furthermore, more accurate injury rates could have been calculated with regard to the player’s role in the team.

Considering the second part of this dissertation, a representative sample of professional male ice hockey players was baseline tested for league normative reference values, and a large two-season test-retest sample was obtained. The study design was implemented within the clinical restrictions of professional ice hockey teams in order to maximize the generalizability and the applicability of the results. We did not use independent external examiners; the testing was done by the teams’ current medical staff. Furthermore, the post-injury SCATs used in the study were completed on the day of injury. By contrast, much of the data of previous research concerning post-injury SCAT performance was collected in delayed onsets – i.e., a day or more later – when the diagnostic utility of the SCAT and its components appears to decrease significantly (McCrea et al. 2013, Chin et al. 2016).

The study also has limitations that should be acknowledged. Previous work suggests that 30–60 concussions occur in the Finnish Ice Hockey League annually (Benson et al. 2011, Tuominen et al. 2017). A limitation of Study IV is that roughly one-fifth of all concussion cases in the league between the 2013–4 and 2015–6 seasons met the selection criteria and were included in the study. This is because each team had an independent practice to follow up injured athletes and only some teams used day-of-injury SCAT testing for the players suspected of suffering from a concussion. Some teams followed other clinical protocols that did not include the
methodology described in this work. Therefore, selection bias may be present. Secondly, the background information of each athlete was based solely on self-report, and therefore might be partly incorrect (Valovich McLeod et al. 2008). Furthermore, important background information (e.g., previous lower limb injuries, neurological problems, sleep history) that might have influenced SCAT performance was not assessed. Finally, the second part of the dissertation focused mainly on the sensitivity of the SCAT with a sample from a very specific group of athletes. Therefore, all these results should be generalized to populations outside professional male ice hockey with great caution, and additional research should be conducted on other sports, levels, genders, age cohorts, and injuries, such as cervical sprains or facial contusions.

Above all, obtaining consistent and detailed injury diagnostics was challenging in both parts of the dissertation. Even so, the same vulnerability exists in all studies concerning concussions due to the deficiency of an explicit definition of the injury and the vague diagnostic criteria.

6.6 Future perspectives

In the future, typical combinations of acute post-injury symptoms should be identified. Linking the typical symptom combinations to objective neurocognitive deficits would establish a greater degree of accuracy in differential diagnostics. Furthermore, early identification of the specific clinical manifestation of concussion would help clinicians to target their post-injury acts more precisely and improve return-to-play time estimations.

Finally, a natural progression for the SCAT5 release would be to analyze the effectiveness of the revisions made. Simultaneously, the evaluation of new on-field and sideline assessments to produce a more valid and clinically relevant SCAT must continue. Additionally, a standardized tool with evidence-based interpretation guidelines specifically designed for the subacute assessment of concussed athletes should be produced for repeated monitoring throughout the rehabilitation process.
In conclusion, the analysis of concussion injury rates in international ice hockey over a nine-season observation period demonstrated a decreasing trend, with an average rate of 7 ice hockey-related concussions per 100 games among professional male players. The corresponding injury rate in female tournaments was 4 per 100 games, while in male junior tournaments the rate was 5 per 100 games. The typical circumstances for a concussive event were consistent with data obtained from the NHL. Most concussions occurred via contact with another player, and a check to the head was the most common cause of injury among male athletes. Almost half of the concussive events occurred near the boards. The risk of concussions associated with board contact decreased significantly when flexible boards and glass were used instead of traditional rink materials.

Ultimately, this dissertation enhances the clinical identification and management of acute sport-related concussions by producing evidence-based recommendations for the interpretation of the Sport Concussion Assessment Tool. Representative SCAT normative reference values for professional male ice hockey players were published. The cutoffs for uncommon performance among uninjured athletes were as follows: Symptom Score=4, Symptom Severity Score=6, SAC Total=24, M-BESS=6, Tandem Gait=12.9. Additionally, the natural distributions of the two-season test-retest difference scores on the SCAT subcomponent baselines were established. The uncommon amount of change in values were as follows: Symptom Score +3 or more, Symptom Severity Score +5 or more, SAC Total -3 or more, M-BESS +3 or more, Tandem Gait +4 seconds or more. The Symptom Scale showed to be the most useful SCAT component in the day-of-injury recognition of concussion. Finally, the day-of-injury SCAT performance was analyzed using two interpretive methods. The post-injury scores were compared (i) to the league normative reference values and (ii) to the athlete’s personal baseline. These interpretation methods demonstrated similar levels of sensitivity in distinguishing between concussed and uninjured athletes. Post-injury impairment identification slightly improved when both methods were used simultaneously.


Burman, E., Lysholm, J., Shahim, P., Malm, C., Tegner Y. 2016,"Concussed athletes are more prone to injury both before and after their index concussion: a data base analysis of 699 concussed contact sports athletes", BMJ Open Sport & Exercise Medicine, doi: 10.1136/bmjsem-2015-000092.


References


McCrory, P., Feddermann-Demont, N., Dvorák, J., Cassidy, J.D., McIntosh, A., Vos, P.E., Echemendia, R.J., Meeuwisse, W., Tarnutzer, A.A. 2017a, "What is the definition of sports-related concussion: a systematic review" British journal of sports medicine vol. 51, no. 11 pp. 877-887.


Patricios, J., Fuller, G.W., Ellenbogen, R., Herring, S., Katcher, J.S., Loosemore, M., Makdissi, M., McCrea, M., Putukian, M. & Schneider, K.J. 2017, "What are the critical elements of sideline screening that can be used to establish the diagnosis of concussion? A systematic review", British journal of sports medicine, Online first: doi: 10.1136/bjsports-2016-097441.


APPENDICES

Appendix 1. Game injury report form of the International Ice Hockey Federation.

Appendix 2. Sport Concussion Assessment Tool – 3rd edition


IIHF Daily Injury Report Form

IIHF Championship: ________________________________

National Association: ______________________________

Date: ___________ / ___________ / ___________ (dd/mm/yy)

Using this form, please report if there were any injuries sustained by any player on your team during the above-mentioned day during this IIHF Championship. We would ask that you also report if there were no injuries sustained by players on your team during this day of this IIHF Championship. If an injury was sustained during this day then an IIHF Injury Report Form must be completed and submitted to the IIHF Medical Supervisor or, in his absence, to the IIHF Directorate Chairman providing the details of the injury sustained.

The definition of an injury used by the IIHF for reporting purposes is as follows:

1. An injury is considered reportable if a player misses a practice or a game because of an injury sustained during a practice or a game
2. The player does not return to the play for the remainder of the game following an injury
3. All concussions
4. All dental injuries
5. Any laceration which requires medical attention
6. All fractures

Please check (√) the appropriate box below. Please provide the number of injuries sustained if you check article 'A'.

<table>
<thead>
<tr>
<th>Injury Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>(√)</td>
</tr>
<tr>
<td>A. During this day there were _____ injuries sustained by our team. (number)</td>
</tr>
<tr>
<td>B. During this day there were no injuries sustained by our team</td>
</tr>
</tbody>
</table>

Team Physician/Medical Representative: ____________________________

(print name)

Signature: ____________________________

Date: ____________________________
What is the SCAT3?1

The SCAT3 is a standardized tool for evaluating injured athletes for concussion and can be used in athletes aged from 13 years and older. It supersedes the original SCAT and the SCAT2 published in 2005 and 2009, respectively. For younger persons, ages 12 and under, please use the Child SCAT3. The SCAT3 is designed for use by medical professionals. If you are not qualified, please use the Sport Concussion Recognition Tool. Preseason baseline testing with the SCAT3 can be helpful for interpreting post-injury test scores.

Specific instructions for use of the SCAT3 are provided on page 3. If you are not familiar with the SCAT3, please read through these instructions carefully. This tool may be freely copied in its current form for distribution to individuals, teams, groups and organizations. Any revision or any reproduction in a digital form requires approval by the Concussion in Sport Group.

NOTE: The diagnosis of a concussion is a clinical judgment, ideally made by a medical professional. The SCAT3 should not be used solely to make, or exclude, the diagnosis of concussion in the absence of clinical judgement. An athlete may have a concussion even if their SCAT3 is “normal”.

What is a concussion?

A concussion is a disturbance in brain function caused by a direct or indirect force to the head. It results in a variety of non-specific signs and/or symptoms (some examples listed below) and most often does not involve loss of consciousness. Concussion should be suspected in the presence of any one or more of the following:

- Symptoms (e.g., headache), or
- Physical signs (e.g., unsteadiness), or
- Impaired brain function (e.g. confusion) or
- Abnormal behaviour (e.g., change in personality).

SIDELINE ASSESSMENT

Indications for Emergency Management

NOTE: A hit to the head can sometimes be associated with a more serious brain injury. Any of the following warrants consideration of activating emergency procedures and urgent transportation to the nearest hospital:

- Glasgow Coma score less than 15
- Deteriorating mental status
- Potential spinal injury
- Progressive, worsening symptoms or new neurologic signs

Potential signs of concussion?

If any of the following signs are observed after a direct or indirect blow to the head, the athlete should stop participation, be evaluated by a medical professional and should not be permitted to return to sport the same day if a concussion is suspected.

Any loss of consciousness?  

Y N

“If so, how long?”  

Balance or motor incoordination (stumbles, slow/laboured movements, etc)?  

Y N

Disorientation or confusion (inability to respond appropriately to questions)?  

Y N

Loss of memory:  

"If so, how long?"  

“Before or after the injury?”  

Blank or vacant look:  

Y N

Visible facial injury in combination with any of the above:  

Y N

Glasgow coma scale (GCS)

Best eye response (E)

No eye opening 1

Eye opening in response to pain 2

Eye opening to speech 3

Eyes opening spontaneously 4

Best verbal response (V)

No verbal response 1

Incomprehensible sounds 2

Inappropriate words 3

Confused 4

Oriented 5

Best motor response (M)

No motor response 1

Extension to pain 2

Abnormal flexion to pain 3

Flexion/Withdrawal to pain 4

Localizes to pain 5

Obeys commands 6

Glasgow Coma score (E + V + M)

of 15

Maddocks Score3

“I am going to ask you a few questions, please listen carefully and give your best effort.”

Modified Maddocks questions (1 point for each correct answer)

What venue are we at today?  

0 1

Which half is it now?  

0 1

Who scored last in this match?  

0 1

What team did you play last week/game?  

0 1

Did your team win the last game?  

0 1

Maddocks score  

of 5

Maddocks score is validated for sideline diagnosis of concussion only and is not used for serial testing.

Notes: Mechanism of Injury (“tell me what happened”):

Any athlete with a suspected concussion should be REMOVED FROM PLAY, medically assessed, monitored for deterioration (i.e., should not be left alone) and should not drive a motor vehicle until cleared to do so by a medical professional. No athlete diagnosed with concussion should be returned to sports participation on the day of Injury.
Appendix 2.

**BACKGROUND**

Name: __________________________ Date: __________________________
Examiner: _______________________
Sport/team/school: __________________________ Date/time of injury: __________________________
Age: __________________________
Gender: M F
Years of education completed: __________________________
Dominant hand: right left neither
How many concussions do you think you have had in the past? __________________________
When was the most recent concussion? __________________________
How long was your recovery from the most recent concussion? __________________________
Have you ever been hospitalized or had medical imaging done for a head injury? Y N
Have you ever been diagnosed with headaches or migraines? Y N
Do you have a learning disability, dyslexia, ADD/ADHD? Y N
Have you ever been diagnosed with depression, anxiety or other psychiatric disorder? Y N
Has anyone in your family ever been diagnosed with any of these problems? Y N
Are you on any medications? If yes, please list: Y N

**SYMPTOM EVALUATION**

SCAT to be done in resting state. Best done 10 or more minutes post exercise.

**How do you feel?**

“You should score yourself on the following symptoms, based on how you feel now.”

<table>
<thead>
<tr>
<th>Symptom</th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headache</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Pressure in head”</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck Pain</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nausea or vomiting</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dizziness</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blurred vision</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balance problems</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity to light</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity to noise</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeling slowed down</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeling like “in a fog”</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Don’t feel right”</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficulty remembering</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue or low energy</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confusion</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drowsiness</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trouble falling asleep</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More emotional</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irritability</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sadness</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nervous or Anxious</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total number of symptoms (Maximum possible 22)

Symptom severity score (Maximum possible 132)

Do the symptoms get worse with physical activity? Y N
Do the symptoms get worse with mental activity? Y N

Overall rating: If you know the athlete well prior to the injury, how different is the athlete acting compared to his/her usual self? Please circle one response:

<table>
<thead>
<tr>
<th>Rating</th>
<th>No different</th>
<th>Very different</th>
<th>Unsure</th>
<th>N/A</th>
</tr>
</thead>
</table>

Scoring on the SCAT3 should not be used as a stand-alone method to diagnose concussion, measure recovery or make decisions about an athlete’s readiness to return to competition after concussion. Since signs and symptoms may evolve over time, it is important to consider repeat evaluation in the acute assessment of concussion.

**COGNITIVE & PHYSICAL EVALUATION**

**Cognitive assessment**

Standardized Assessment of Concussion (SAC)4

Orientation (1 point for each correct answer)

<table>
<thead>
<tr>
<th>What month is it?</th>
<th>0 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the date today?</td>
<td>0 1</td>
</tr>
<tr>
<td>What is the day of the week?</td>
<td>0 1</td>
</tr>
<tr>
<td>What year is it?</td>
<td>0 1</td>
</tr>
<tr>
<td>What time is it right now? (within 1 hour)</td>
<td>0 1</td>
</tr>
</tbody>
</table>

Orientation score ___________ of 5

Immediate memory

<table>
<thead>
<tr>
<th>List</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Alternative word list</th>
</tr>
</thead>
<tbody>
<tr>
<td>elbow</td>
<td>0 1 0 1 0 1</td>
<td>candle</td>
<td>baby</td>
<td>finger</td>
</tr>
<tr>
<td>apple</td>
<td>0 1 0 1 0 1</td>
<td>paper</td>
<td>monkey</td>
<td>penny</td>
</tr>
<tr>
<td>carpet</td>
<td>0 1 0 1 0 1</td>
<td>sugar</td>
<td>perfume</td>
<td>blanket</td>
</tr>
<tr>
<td>saddle</td>
<td>0 1 0 1 0 1</td>
<td>sandwich</td>
<td>sunset</td>
<td>lemon</td>
</tr>
<tr>
<td>bubble</td>
<td>0 1 0 1 0 1</td>
<td>wagon</td>
<td>iron</td>
<td>insect</td>
</tr>
</tbody>
</table>

Total Immediate memory score total ___________ of 15

Concentration: Digits Backward

<table>
<thead>
<tr>
<th>List</th>
<th>Trial 1</th>
<th>Alternative digit list</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-9-3</td>
<td>0 1</td>
<td>6-2-9</td>
</tr>
<tr>
<td>3-8-1-4</td>
<td>0 1</td>
<td>3-2-7-9</td>
</tr>
<tr>
<td>6-2-9-7-1</td>
<td>0 1</td>
<td>1-5-2-8-6</td>
</tr>
<tr>
<td>7-1-8-4-6-2</td>
<td>0 1</td>
<td>5-3-9-1-4-8</td>
</tr>
<tr>
<td>Total of 4</td>
<td></td>
<td>4-1-5</td>
</tr>
</tbody>
</table>

Concentration: Month in Reverse Order (1 pt. for entire sequence correct)


**Neck Examination:**

Range of motion Tenderness Upper and lower limb sensation & strength

Findings:

**Balance examination**

Do one or both of the following tests.

Footwear (shoes, barefoot, braces, tape, etc.)

Modified Balance Error Scoring System (BESS) testing4

Which foot was tested (i.e. which is the non-dominant foot) Left Right

Testing surface (hard floor, field, etc.)

Condition

Double leg stance: Errors

Single leg stance (non-dominant foot): Errors

Tandem stance (non-dominant foot at back): Errors

And/Or

Tandem gait4, 5 Time (best of 4 trials): ___________ seconds

**Coordination examination**

Upper limb coordination

Which arm was tested: Left Right

Coordination score ___________ of 1

**SAC Delayed Recall4**

Delayed recall score ___________ of 5
INSTRUCTIONS

Words in italics throughout the SCAT3 are the instructions given to the athlete by the tester.

Symptom Scale

“You should score yourself on the following symptoms, based on how you feel now”.

To be completed by the athlete. In situations where the symptom scale is being completed after exercise, it should still be done in a resting state, at least 10 minutes post exercise.

For total number of symptoms, maximum possible is 22.

For Symptom severity score, add all scores in table, maximum possible is 22 x 6 = 132.

SAC4

Immediate Memory

“I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order.”

Trials 2 & 3:

“I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before.”

Complete all 3 trials regardless of score on trial 1 & 2. Read the words at a rate of one per second.

Score 1 pt. for each correct response. Total score equals sum across all 3 trials. Do not inform the athlete that delayed recall will be tested.

Concentration

Digits backward

“I am going to read you a string of numbers and when I am done, you repeat them back to me backwards, in reverse order of how I read them to you. For example, if I say 7-1-5, you would say 9-1-7.”

If correct, go to next string length. If incorrect, read trial 2. One point possible for each string length. Stop after incorrect on both trials. The digits should be read at the rate of one per second.

Months in reverse order

“Now tell me the months of the year in reverse order. Start with the last month and go backward. So you’ll say December, November...”

1 pt. for entire sequence correct

Delayed Recall

The delayed recall should be performed after completion of the Balance and Coordination Examinations.

“Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order.”

Score 1 pt. for each correct response

Balance Examination

Modified Balance Error Scoring System (BESS) testing

This balance testing is based on a modified version of the Balance Error Scoring System (BESS)©. A stopwatch or watch with a second hand is required for this testing.

“I am now going to test your balance. Please take your shoes off, roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty second tests with different stances.”

(a) Double leg stance:

“The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes.”

(b) Single leg stance:

“If you were to kick a ball, which foot would you use? (This will be the dominant foot) Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes.”

(c) Tandem stance:

“Now stand heel-to-toe with your non-dominant foot in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes.”

Balance testing – types of errors

1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of test position > 5 sec

Each of the 20-second trials is scored by counting the errors, or deviations from the proper stance, accumulated by the athlete. The examiner will begin counting errors only after the individual has assumed the proper start position. The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum total number of errors for any single condition is 10. If a athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once subject is set. Subjects that are unable to maintain the testing procedure for a minimum of five seconds at the start are assigned the highest possible score, ten, for that testing condition.

OPTION: For further assessment, the same 3 stances can be performed on a surface of medium density foam (e.g., approximately 50 cm x 40 cm x 6 cm).

Tandem Gait©

Participants are instructed to stand with their feet together behind a starting line (the test is best done with footwear removed). Then, they walk in a forward direction as quickly and as accurately as possible along a 38mm wide (sports tape), 3 meter line with an alternate foot heel-to-toe gait ensuring that they approximate their heel and toe on each step. Once they cross the end of the 3m line, they turn 180 degrees and return to the starting point using the same gait. A total of 4 trials are done and the best time is retained. Athletes should complete the test in 14 seconds. Athletes fail the test if they step off the line, have a separation between their heel and toe, or if they touch or grab the examiner or an object. In this case, the time is not recorded and the trial repeated, if appropriate.

Coordination Examination

Upper limb coordination

Finger-to-nose (FTN) task:

“I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended), pointing in front of you. When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose, and then return to the starting position, as quickly and as accurately as possible.”

Scoring: 5 correct repetitions in ≤ 4 seconds = 1

Note for testers: Athletes fail the test if they do not touch their nose, do not fully extend their elbow or do not perform five repetitions. Failure should be scored as 0.

References & Footnotes

1. This tool has been developed by a group of international experts at the 4th International Consensus meeting on Concussion in Sport held in Zurich, Switzerland in November 2012. The full details of the conference outcomes and the authors of the tool are published in The BJSIM Injury Prevention and Health Protection, 2013, Volume 47, Issue 5. The outcome paper will also be simultaneously co-published in other leading biomedical journals with the copyright held by the Concussion in Sport Group, to allow unrestricted distribution, providing no alterations are made.


ATHLETE INFORMATION
Any athlete suspected of having a concussion should be removed from play, and then seek medical evaluation.

Signs to watch for
Problems could arise over the first 24–48 hours. The athlete should not be left alone and must go to a hospital at once if they:
- Have a headache that gets worse
- Are very drowsy or can't be awakened
- Can't recognize people or places
- Have repeated vomiting
- Behave unusually or seem confused; are very irritable
- Have seizures (arms and legs jerk uncontrollably)
- Have weak or numb arms or legs
- Are unsteady on their feet; have slurred speech
Remember, it is better to be safe. Consult your doctor after a suspected concussion.

Return to play
Athletes should not be returned to play the same day of injury. When returning athletes to play, they should be medically cleared and then follow a stepwise supervised program, with stages of progression.

For example:

<table>
<thead>
<tr>
<th>Rehabilitation stage</th>
<th>Functional exercise at each stage of rehabilitation</th>
<th>Objective of each stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No activity</td>
<td>Physical and cognitive rest</td>
<td>Recovery</td>
</tr>
<tr>
<td>Light aerobic exercise</td>
<td>Walking, swimming or stationary cycling keeping intensity, 70% maximum predicted heart rate. No resistance training</td>
<td>Increase heart rate</td>
</tr>
<tr>
<td>Sport-specific exercise</td>
<td>Skating drills in ice hockey, running drills in soccer. No head impact activities</td>
<td>Add movement</td>
</tr>
<tr>
<td>Non-contact training drills</td>
<td>Progression to more complex training drills, eg passing drills in football and ice hockey. May start progressive resistance training</td>
<td>Exercise, coordination, and cognitive load</td>
</tr>
<tr>
<td>Full contact practice</td>
<td>Following medical clearance participate in normal training activities</td>
<td>Restore confidence and assess functional skills by coaching staff</td>
</tr>
<tr>
<td>Return to play</td>
<td>Normal game play</td>
<td></td>
</tr>
</tbody>
</table>

There should be at least 24 hours (or longer) for each stage and if symptoms recur the athlete should rest until they resolve once again and then resume the program at the previous asymptomatic stage. Resistance training should only be added in the later stages.

If the athlete is symptomatic for more than 10 days, then consultation by a medical practitioner who is expert in the management of concussion, is recommended.

Medical clearance should be given before return to play.

CONCUSSION INJURY ADVICE
(To be given to the person monitoring the concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. Recovery time is variable across individuals and the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, dizziness, worsening headache, double vision or excessive drowsiness, please contact your doctor or the nearest hospital emergency department immediately.

Other important points:
- Rest (physically and mentally), including training or playing sports until symptoms resolve and you are medically cleared
- No alcohol
- No prescription or non-prescription drugs without medical supervision.
  Specifically:
  · No sleeping tablets
  · Do not use aspirin, anti-inflammatory medication or sedating pain killers
  · Do not drive until medically cleared
  · Do not train or play sport until medically cleared

Clinic phone number

Scoring Summary:

<table>
<thead>
<tr>
<th>Test Domain</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date:</td>
<td></td>
</tr>
<tr>
<td>Date:</td>
<td></td>
</tr>
<tr>
<td>Date:</td>
<td></td>
</tr>
</tbody>
</table>

Number of Symptoms of 22
Symptom Severity Score of 132
Orientation of 5
Immediate Memory of 15
Concentration of 5
Delayed Recall of 5
SAC Total
BESS (total errors)
Tandem Gait (seconds)
Coordination of 1

Notes:

Patient’s name
Date/time of injury
Date/time of medical review
Treating physician

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Mikä on SCAT3?1


HUOM! Aivotärähdys-diagnoosi on klininen arvio, jonka hänentapauksessa tekeen terveydenhuollon ammattilainen. SCAT3-mittaria ei tule yksistään käyttää mahdollisen aivotärähdyn korjaamaan tai poispuoltemiseen silloin, kun kliniinen arviointi ei ole mahdollista. Urheilijalla voi olla aivotärähdys, vaikka hänen SCAT3-tuloksensa on ”normaali”.

Mikä on aivotärähdys?

Aivotärähdys on päähän kohdistuvan suoran tai epäsuoran voiman aiheuttama Vammautumismekanismi. Aivotärähdys on päähän kohdistuvan suoran tai epäsuoran voiman aiheuttama Vammautumismekanismi.

Mikä on aivotärähdys?

Aivotärähdys on päähän kohdistuvan suoran tai epäsuoran voiman aiheuttama. Aivotärähdys-diaagnose on klininen arvio, jonka hänentapauksessa tekeen terveydenhuollon ammattilainen. SCAT3-mittaria ei tule yksistään käyttää mahdollisen aivotärähdyn toteamiseen tai poispuoltemiseen silloin, kun kliniinen arviointi ei ole mahdollista. Urheilijalla voi olla aivotärähdys, vaikka hänen SCAT3-tuloksensa on ”normaali”.

Mikä on aivotärähdys?

Aivotärähdys on päähän kohdistuvan suoran tai epäsuoran voiman aiheuttama. Aivotärähdys-diaagnose on klininen arvio, jonka hänentapauksessa tekeen terveydenhuollon ammattilainen. SCAT3-mittaria ei tule yksistään käyttää mahdollisen aivotärähdyn toteamiseen tai poispuoltemiseen silloin, kun kliniinen arviointi ei ole mahdollista. Urheilijalla voi olla aivotärähdys, vaikka hänen SCAT3-tuloksensa on ”normaali”.

KENTÄNREUNA-ARVIOINTI

Hätätilanteiden hallinta

HUOM! Päähän kohdistunut isku voi joskus aiheuttaa vakavan vammoan. Mikä tahansa seuraavista on pätevän syy harkittavaksi häiriöiden aiheuttamasta ja välitöntä kuljetusta lähimpään sairaalaan:

- Glasgow Coma Scale -pistemäärä, joka on alle 15
- Henkisen tilan heikkeneminen
- Mahdollinen sekäkäydinvamma
- Etenevat, pahenevat oireet tai uudet neurologiset löydökset

Mahdollisia aivotärähdyn oireita?

Minkä tahansa seuraavien oireiden ilmetessä päähän kohdistuneen suoran tai epäsuoran iskin jälkeen, urheilijan tulee poistua kentältä, terveydenhuollon ammatillisen tulee tutkia hänet eikä hän saa osallistua urheiluun sinä päivänä, jona hänen epäillään saaneen aivotärähdystä.
Appendix 3.

**TAUSTA**

Nimi: Päivämäärä:

Testin tekijä:

Laji/joukkue (koulu):

Loukkautumisen pvm/klo: Sukupuoli: M N

Koulutusvuosien määrä:

Käytässä:

Oikea

Vasen

Ei kumpikaan

Kuinka monta aivotärähdystä uskot saaneesi aiemmin?

Psykiatrinen häiriö?

Käy

Kär

o

n

Kou

Ei tule perustua pelkästään SCAT3-pistemäärään. Koska oireet akankevatko oireet fyysisen suorituksen aikana?

Oireiden arviointi

Yhteensä

Keskittymisvaikeuksia

Sekavuutta

Surullisuutta

Päänsärkyä

”Paineentunnetta päässä”

Niskakipua

Pahoinvointia tai oksentelua

Huimausta

Näön hämärästä

Tasapainon-ongelmia

Valoherkkyyttä

Meluhervakkyyttä

Kaikki tapahtuu kuin hidastettuna

Tuntuu kuin kulkisi sumussa

”Ei tunnu normaalilta”

Keskittymisyväkeukseks

Muistiveukseks

Väsymystä tai voimattomuuden tunnetta

Sekavuutta

Unelaisuuutta

Nukaherttuvuutta

Tavalista tunnehkempi

Ärtyisyyttä

Surullisuutta

Hermoalasuuutta tai ahdistuneisuutta

Oireiden kokonaismäärä (maximi 22p)

Oireiden voimakkuuden pistemäärä (maximi 132p)

Pahenevat oireet fyysisen suorituksen aikana?

Pahenevat oireet henkisen suorituksen aikana?

Oma arvio

Kliinin valvonnassa

Vain valvonta

Oma arvio

Kliinin haastattelu

Oma, vanhemman valvontamiehen

Yleisarviointi: Jos tunnet urheilijan hyvin jo loukkautumista edeltävältä ajalta, miten paljon hänen käyttökeskensä eroaa tavallisesta?

Yleisarviointi: Jos tunnet urheilijan hyvin jo loukkautumista edeltävältä ajalta, miten paljon hänen käyttökeskensä eroaa tavallisesta?

Appendix 3.

**KOGNITIIVINEN JA FYSINEN ARVIOINTI**

4 Kognitiivinen arviointi

Standardized Assessment of Concussion (SAC)

**Orientaatio** (1 piste jokaisesta oikeasta vastauksesta)

Mikä kuukausi nyt on?

Miksi pelkkää nyt?

Miksi viikonpäivää nyt?

Mikä vuosi nyt on?

Paljonko kello on? (tunnin tarkkuudella)

Orientaation pistemäärä

/5

Lähiimuisti

Keskittymisen pistemäärä

/15

Keskittyminen: Numerot takaperin

Keskittyminen: Kukkaudet käännetyssä järjestyksessä

Keskittymisen pistemäärä

/5

Kaulan tutkiminen:

Lukionäkyus: Arkuus

Ylä- ja alaraajojen tunto ja voima

Havainnot:

Tasapainotutkimus

Suora toinen tai molemmat senaattotulosten testistä. Taulukon (kengä, jalas, paljan jalo, tukien kanta, teipattuna jne.)

Modifioitu Balance Error Scoring System-testi

Kumpi jalka testattiin (ts. ei-hallitseva jalka)

Testausalusta (kova lattia, pelikenttä jne.)

Testi

Kahden jalan asento

Yhden jalan asento (ei-hallitseva jalka)

Tandem-asento (ei-hallitseva jalka takana)

Ja / Tai

Tandem-kävely

Aika (paras 4:stä testistä)

/5

Koordinaatiotutkimus

Yläraajojen koordinaatio

Kumpi käsi testattiin:

Koordinaatiotestin pistemäärä

/3

Viivästynyt muisti

Viivästynyn muistin pistemäärä

/5

SCAT3 SPORT CONCUSSION ASSESSMENT TOOL 3 | SIVU 2

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Aivotärähdyksen diagnosoinnin, siitä toipumisen tai päättöisten urheilijan valmiudesta osallistua kilpailuun aivotärähdyksen jälkeen ei tule peruuttaa pelkästään SCAT3-pistemäärään. Koska oireet voivat muuttua ajan mittaan, on tärkeää harkita uudelleenarviointia aivotärähdyksen akutissua arvioinnissä.
OHJEET

Testin tekiän urheilijalle antamat ohjet on SCAT3-lomakkeella kirjoitettu kurssivilla.

Oireasteikko

"Sinun tulee antaa itseesi pisteitä seuraavien oireiden suhteen sen perusteella mitä sinusta nyt tunnetu."


SAC4 Lähimuisti

"Aion testata muistiisi. Luen sinulle listan sanoja ja pyydän, että sen jälkeen toistan niistä monta sanaa kuin muistat missä järjestysessä tahansa."


Keskitiiminen

 numero testakenein

"Luen nyt numerokortin. Kun olen lopettanut, toista numerokortin pääsääntöä kerran ja pyydän, että pystyt muistamaan numerokortin pistemääritä." pistesarjojen

"Muistatko aikaisemmin lukemani sanalistan? Luettele niin monta sanaa listasta kuin menetäksit kylpemässä Harjalla.

Keskittyminen

Annetaan 1 piste kustakin oikeasta vastauksesta.

Suorita kaikki testit vastaamatta minulle pistemääristä riippumatta. Luettele sanat yhden sekunnin yhteydessä. Älä kerro urheilijalle, että viiviät viitataan tarpeelliseksi.

Koordinaatiotutkimus

Yläraajojen koordinaatio

Sormen-luonomatka

"Pisteytys: 5 oikeaa toistoa < 4 sekunnissa = 1p. Huomautus: Testin tekiänä: Urheilijat eivät läpäise testia, jos he eivät vastaa minimin vaatimuksia, eikä paitsi vastaavat

Viitteet ja alaviitteet

1. Tämä arviointilomake on kehittetty Zürichissä marraskuussa 2012 pitkäisessä järjestelyyn sisäestetyn ja muistiosien


TIETOJA URHEILJALLE

Jos epäillään aivotärähdystä, urheilija on välittömästi otettava pois terveydentilaansa ja hänet on viettävä sairaalaan heti, jos:
- Päänsärky pahenee
- Hän on unelias tai häntä ei saada hereille
- Hän ei tunnista ihmisiä tai paikkoja
- Hän oskentelee toistuvasti
- Hän käyttäytyy uudosti tai vaikuttaa sekaavalla; on hyvin arvyksia
- Hän saa kohtauksia (käsivarrat ja jalat nykivät hallitsemattomasti)
- Hänen käsissavartensa tai jalkavartensa tulevat voimattomiiksi tai tunnottomiksi
- Hän ei tahdosta pysyä jaloiilla; puheensa on epäselvää

Muista: koskaan ei voi olla liian varovainen.

Jos epäillään aivotärähdystä, käänny lääkärin puoleen.

Kokonaispistemäärä

<table>
<thead>
<tr>
<th>Testivalo</th>
<th>Pistemäärä</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oireiden lukumäärä (maks. 22)</td>
<td></td>
</tr>
<tr>
<td>Oireiden vakavuuden pistemäärä (maks. 132)</td>
<td></td>
</tr>
<tr>
<td>Orientaation pistemäärä (maks. 5)</td>
<td></td>
</tr>
<tr>
<td>Lähimuistin pistemäärä (maks. 15)</td>
<td></td>
</tr>
<tr>
<td>Keskeyttämisen pistemäärä (maks. 5)</td>
<td></td>
</tr>
<tr>
<td>Viivästynuon muistin pistemäärä (maks. 5)</td>
<td></td>
</tr>
<tr>
<td>SAC-pistemäärä</td>
<td></td>
</tr>
</tbody>
</table>

Muistiinpanoja:

- Älä ota rasitusaineita ennen kuin lääkäri on todennut sinut terveeksi
- Älä ajaa autona ennen kuin lääkäri on todennut sinut terveeksi
- Älä ottaa reseptilääkkeitä ilman lääkärin lupaa

Yhteystiedot tai leima

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Appendix 3.

TARKKAILTAVIA OIREITA

Oireita saattaa ilmetä loukkaantumista seuraavan 24–48 tunnin kuluessa. Urheilija ei saa jättää yksin ja hänet on viettävä sairaalaan heti, jos:

- Päänsärky pahenee
- Hän on unelias tai häntä ei saada hereille
- Hän ei tunnista ihmisiä tai paikkoja
- Hän oskentelee toistuvasti
- Hän käyttäytyy uudosti tai vaikuttaa sekaavalla; on hyvin arvyksia
- Hän saa kohtauksia (käsivarrat ja jalat nykivät hallitsemattomasti)
- Hänen käsissavartensa tai jalkavartensa tulevat voimattomiiksi tai tunnottomiksi
- Hän ei tahdosta pysyä jaloiilla; puheensa on epäselvää

Muista: koskaan ei voi olla liian varovainen.

Jos epäillään aivotärähdystä, käänny lääkärin puoleen.

Paluu urheilun pariin

Loukkaantunutta urheilija ei saa päästää pelaamaan sinä päivänä, jona loukkaantuminen on tapahtunut. Paluu urheilun pariin tulee tapahtua lääkärin luvulla vaiheitain ja valvottu.

Muuta huomioitavaa:
- Älä huomioi aivotärähdystä arvioimalla kunnostavamme
- Jokaisen paluun pariin tulee tapahtua lääkärin luvulla vaiheittain ja valvottu.

Muistiinpanoja:

- Älä ota rasitusaineita ennen kuin lääkäri on todennut sinut terveeksi
- Älä ajaa autona ennen kuin lääkäri on todennut sinut terveeksi
- Älä otta reseptilääkkeitä ilman lääkärin lupaa

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SAC-pistemäärä

Muistiinpanoja:

- Älä ota rasitusaineita ennen kuin lääkäri on todennut sinut terveeksi
- Älä ajaa autona ennen kuin lääkäri on todennut sinut terveeksi
- Älä ottaa reseptilääkkeitä ilman lääkärin lupaa

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WHAT IS THE SCAT5?

The SCAT5 is a standardized tool for evaluating concussions designed for use by physicians and licensed healthcare professionals. The SCAT5 cannot be performed correctly in less than 10 minutes.

If you are not a physician or licensed healthcare professional, please use the Concussion Recognition Tool 5 (CRT5). The SCAT5 is to be used for evaluating athletes aged 13 years and older. For children aged 12 years or younger, please use the Child SCAT5.

Preseason SCAT5 baseline testing can be useful for interpreting post-injury test scores, but is not required for that purpose. Detailed instructions for use of the SCAT5 are provided on page 7. Please read through these instructions carefully before testing the athlete. Brief verbal instructions for each test are given in italics. The only equipment required for the tester is a watch or timer.

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Recognise and Remove

A head impact by either a direct blow or indirect transmission of force can be associated with a serious and potentially fatal brain injury. If there are significant concerns, including any of the red flags listed in Box 1, then activation of emergency procedures and urgent transport to the nearest hospital should be arranged.

Key points

- Any athlete with suspected concussion should be REMOVED FROM PLAY, medically assessed and monitored for deterioration. No athlete diagnosed with concussion should be returned to play on the day of injury.
- If an athlete is suspected of having a concussion and medical personnel are not immediately available, the athlete should be referred to a medical facility for urgent assessment.
- Athletes with suspected concussion should not drink alcohol, use recreational drugs and should not drive a motor vehicle until cleared to do so by a medical professional.
- Concussion signs and symptoms evolve over time and it is important to consider repeat evaluation in the assessment of concussion.
- The diagnosis of a concussion is a clinical judgment, made by a medical professional. The SCAT5 should NOT be used by itself to make, or exclude, the diagnosis of concussion. An athlete may have a concussion even if their SCAT5 is “normal”.

Remember:

- The basic principles of first aid (danger, response, airway, breathing, circulation) should be followed.
- Do not attempt to move the athlete (other than that required for airway management) unless trained to do so.
- Assessment for a spinal cord injury is a critical part of the initial on-field assessment.
- Do not remove a helmet or any other equipment unless trained to do so safely.
IMMEDIATE OR ON-FIELD ASSESSMENT

The following elements should be assessed for all athletes who are suspected of having a concussion prior to proceeding to the neurocognitive assessment and ideally should be done on-field after the first first aid / emergency care priorities are completed.

If any of the “Red Flags” or observable signs are noted after a direct or indirect blow to the head, the athlete should be immediately and safely removed from participation and evaluated by a physician or licensed healthcare professional.

Consideration of transportation to a medical facility should be at the discretion of the physician or licensed healthcare professional.

The GCS is important as a standard measure for all patients and can be done serially if necessary in the event of deterioration in conscious state. The Maddocks questions and cervical spine exam are critical steps of the immediate assessment; however, these do not need to be done serially.

STEP 1: RED FLAGS

RED FLAGS:
- Neck pain or tenderness
- Double vision
- Weakness or tingling/numbness in arms or legs
- Severe or increasing headache
- Seizure or convulsion
- Loss of consciousness
- Deteriorating conscious state
- Vomiting
- Increasingly restless, agitated or combative

STEP 2: OBSERVABLE SIGNS

Witnessed ☐ Observed on Video ☐
- Lying motionless on the playing surface Y N
- Balance / gait difficulties / motor incoordination: stumbling, slow / laboured movements Y N
- Disorientation or confusion, or an inability to respond appropriately to questions Y N
- Blank or vacant look Y N
- Facial injury after head trauma Y N

STEP 3: MEMORY ASSESSMENT

Maddock’s Questions:

"I am going to ask you a few questions, please listen carefully and give your best effort. First, tell me what happened?"

Mark Y for correct answer / N for incorrect
- What venue are we at today? Y N
- Which half is it now? Y N
- Who scored last in this match? Y N
- What team did you play last week / game? Y N
- Did your team win the last game? Y N

STEP 4: EXAMINATION

GLASGOW COMA SCALE (GCS)

Time of assessment
Date of assessment

Best eye response (E)
- No eye opening 1 1 1
- Eye opening in response to pain 2 2 2
- Eye opening to speech 3 3 3
- Eyes opening spontaneously 4 4 4

Best verbal response (V)
- No verbal response 1 1 1
- Incomprehensible sounds 2 2 2
- Inappropriate words 3 3 3
- Confused 4 4 4
- Oriented 5 5 5

Best motor response (M)
- No motor response 1 1 1
- Extension to pain 2 2 2
- Abnormal flexion to pain 3 3 3
- Flexion / Withdrawal to pain 4 4 4
- Localizes to pain 5 5 5
- Obeys commands 6 6 6

Glasgow Coma score (E + V + M)

CERVICAL SPINE ASSESSMENT

- Does the athlete report that their neck is pain free at rest? Y N
- If there is NO neck pain at rest, does the athlete have a full range of ACTIVE pain free movement? Y N
- Is the limb strength and sensation normal? Y N

In a patient who is not lucid or fully conscious, a cervical spine injury should be assumed until proven otherwise.

Appendix 4.
OFFICE OR OFF-FIELD ASSESSMENT

Please note that the neurocognitive assessment should be done in a distraction-free environment with the athlete in a resting state.

STEP 1: ATHLETE BACKGROUND

Sport / team / school: ________________________________
Date / time of injury: ________________________________
Years of education completed: ________________________
Age: _____________________
Gender: M / F / Other
Dominant hand: left / neither / right
How many diagnosed concussions has the athlete had in the past?: ________________________
When was the most recent concussion?: ________________________
How long was the recovery (time to being cleared to play) from the most recent concussion?: ________________________ (days)

Has the athlete ever been:

Hospitalized for a head injury? Yes No
Diagnosed / treated for headache disorder or migraines? Yes No
Diagnosed with a learning disability / dyslexia? Yes No
Diagnosed with ADD / ADHD? Yes No
Diagnosed with depression, anxiety or other psychiatric disorder? Yes No

Current medications? If yes, please list:


STEP 2: SYMPTOM EVALUATION

The athlete should be given the symptom form and asked to read this instruction paragraph out loud then complete the symptom scale. For the baseline assessment, the athlete should rate his/her symptoms based on how he/she typically feels and for the post injury assessment the athlete should rate their symptoms at this point in time.

Please Check: □ Baseline □ Post-Injury

Please hand the form to the athlete

<table>
<thead>
<tr>
<th>Symptom</th>
<th>none</th>
<th>mild</th>
<th>moderate</th>
<th>severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headache</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>&quot;Pressure in head&quot;</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Neck Pain</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Nausea or vomiting</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Dizziness</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Blurred vision</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Balance problems</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Sensitivity to light</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Sensitivity to noise</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Feeling slowed down</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Feeling like &quot;in a fog&quot;</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>&quot;Don't feel right&quot;</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Difficulty remembering</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Fatigue or low energy</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Confusion</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Drowsiness</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>More emotional</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Irritability</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Sadness</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Nervous or Anxious</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Trouble falling asleep (if applicable)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Total number of symptoms: __________ of 22
Symptom severity score: __________ of 132
Do your symptoms get worse with physical activity? Y N
Do your symptoms get worse with mental activity? Y N
If 100% is feeling perfectly normal, what percent of normal do you feel?

If not 100%, why?

Please hand form back to examiner

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STEP 3: COGNITIVE SCREENING
Standardised Assessment of Concussion (SAC)4

ORIENTATION

<table>
<thead>
<tr>
<th>Question</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>What month is it?</td>
<td>0</td>
</tr>
<tr>
<td>What is the date today?</td>
<td>0</td>
</tr>
<tr>
<td>What is the day of the week?</td>
<td>0</td>
</tr>
<tr>
<td>What year is it?</td>
<td>0</td>
</tr>
<tr>
<td>What time is it right now? (within 1 hour)</td>
<td>0</td>
</tr>
</tbody>
</table>

Orientation score: of 5

IMMEDIATE MEMORY

The Immediate Memory component can be completed using the traditional 5-word per trial list or optionally using 10-words per trial to minimise any ceiling effect. All 3 trials must be administered irrespective of the number correct on the first trial. Administer at the rate of one word per second.

Please choose EITHER the 5 or 10 word list groups and circle the specific word list chosen for this test.

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order. For Trials 2 & 3, I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before.

Immediate Memory Score: of 15

<table>
<thead>
<tr>
<th>List</th>
<th>Alternate 5 word lists</th>
<th>Score (of 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Finger Penny Blanket Lemon</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Candle Paper Sugar Sandwich</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Baby Monkey Perfume Sunset</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Elbow Apple Carpet Saddle Bubble</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Jacket Arrow Pepper Cotton Movie</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Dollar Honey Mirror Saddle Anchor</td>
<td></td>
</tr>
</tbody>
</table>

Immediate Memory Score: of 15

<table>
<thead>
<tr>
<th>List</th>
<th>Alternate 10 word lists</th>
<th>Score (of 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>Finger Penny Blanket Lemon</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Baby Monkey Perfume Sunset</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Jacket Arrow Pepper Cotton Movie</td>
<td></td>
</tr>
</tbody>
</table>

Immediate Memory Score: of 15

CONCENTRATION

DIGITS BACKWARDS

Please circle the Digit list chosen (A, B, C, D, E, F). Administer at the rate of one digit per second reading DOWN the selected column.

I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.

Concentration Number Lists (circle one)

<table>
<thead>
<tr>
<th>List A</th>
<th>List B</th>
<th>List C</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-9-3</td>
<td>5-2-6</td>
<td>1-4-2</td>
</tr>
<tr>
<td>6-2-9</td>
<td>4-1-5</td>
<td>6-5-8</td>
</tr>
<tr>
<td>3-8-1-4</td>
<td>1-7-9-5</td>
<td>6-8-3-1</td>
</tr>
<tr>
<td>3-2-7-9</td>
<td>4-9-6-8</td>
<td>3-4-8-1</td>
</tr>
<tr>
<td>6-2-9-71</td>
<td>4-8-5-2-7</td>
<td>4-9-1-5-3</td>
</tr>
<tr>
<td>1-5-2-8-6</td>
<td>6-1-8-4-3</td>
<td>6-8-5-1</td>
</tr>
<tr>
<td>7-1-8-4-6-2</td>
<td>8-3-1-9-6-4</td>
<td>3-7-6-5-1-9</td>
</tr>
<tr>
<td>5-3-9-1-4-8</td>
<td>7-2-4-8-5-6</td>
<td>9-2-6-5-1-4</td>
</tr>
</tbody>
</table>

Immediate Memory Score: of 30

Time that last trial was completed

List D | List E | List F
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7-8-2</td>
<td>3-8-2</td>
<td>2-7-1</td>
</tr>
<tr>
<td>9-2-6</td>
<td>5-1-8</td>
<td>4-7-9</td>
</tr>
<tr>
<td>4-1-8-3</td>
<td>2-7-9-3</td>
<td>1-6-8-3</td>
</tr>
<tr>
<td>9-7-2-3</td>
<td>2-1-6-9</td>
<td>3-9-2-4</td>
</tr>
<tr>
<td>1-7-9-2-6</td>
<td>4-1-8-6-9</td>
<td>2-4-7-5-8</td>
</tr>
<tr>
<td>4-1-7-5-2</td>
<td>9-4-1-7-5</td>
<td>8-3-9-6-4</td>
</tr>
<tr>
<td>2-6-4-8-1-7</td>
<td>6-9-7-3-8-2</td>
<td>5-8-6-2-4-9</td>
</tr>
<tr>
<td>8-4-1-9-3-5</td>
<td>4-2-7-9-3-8</td>
<td>3-1-7-8-2-6</td>
</tr>
</tbody>
</table>

Digits Score: of 4

MONTHS IN REVERSE ORDER

Now tell me the months of the year in reverse order. Start with the last month and go backward. So you’ll say December, November. Go ahead.


Months Score: of 1

Concentration Total Score (Digits + Months): of 5

Name: ________________________________
DOB: ________________________________
Address: _____________________________
ID number: ___________________________
Examiner: ____________________________
Date: ________________________________

Appendix 4.

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**STEP 4: NEUROLOGICAL SCREEN**

See the instruction sheet (page 7) for details of test administration and scoring of the tests.

<table>
<thead>
<tr>
<th>Question</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can the patient read aloud (e.g. symptom checklist) and follow instructions without difficulty?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Does the patient have a full range of pain-free PASSIVE cervical spine movement?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Without moving their head or neck, can the patient look side-to-side and up-and-down without double vision?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Can the patient perform the finger nose coordination test normally?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Can the patient perform tandem gait normally?</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

**BALANCE EXAMINATION**

Modified Balance Error Scoring System (mBESS) testing

<table>
<thead>
<tr>
<th>Condition</th>
<th>Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double leg stance</td>
<td>of 10</td>
</tr>
<tr>
<td>Single leg stance (non-dominant foot)</td>
<td>of 10</td>
</tr>
<tr>
<td>Tandem stance (non-dominant foot at the back)</td>
<td>of 10</td>
</tr>
<tr>
<td>Total Errors</td>
<td>of 30</td>
</tr>
</tbody>
</table>

**STEP 5: DELAYED RECALL:**

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section. Score 1 pt. for each correct response.

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order.

**Total number of words recalled accurately:** of 5 or of 10

**STEP 6: DECISION**

<table>
<thead>
<tr>
<th>Domain</th>
<th>Date &amp; time of assessment:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptom number (of 22)</td>
<td></td>
</tr>
<tr>
<td>Symptom severity score (of 132)</td>
<td></td>
</tr>
<tr>
<td>Orientation (of 5)</td>
<td></td>
</tr>
<tr>
<td>Immediate memory</td>
<td>of 15 of 30 of 15 of 30 of 15 of 30</td>
</tr>
<tr>
<td>Concentration (of 5)</td>
<td></td>
</tr>
<tr>
<td>Neuro exam</td>
<td>Normal Abnormal Normal Abnormal Normal Abnormal</td>
</tr>
<tr>
<td>Balance errors (of 30)</td>
<td>of 5 of 10 of 5 of 10 of 5 of 10</td>
</tr>
<tr>
<td>Delayed Recall</td>
<td></td>
</tr>
</tbody>
</table>

Date and time of injury: ____________________________

If the athlete is known to you prior to their injury, are they different from their usual self?

☐ Yes ☐ No ☐ Unsure ☐ Not Applicable

(If different, describe why in the clinical notes section)

Concussion Diagnosed?

☐ Yes ☐ No ☐ Unsure ☐ Not Applicable

If re-testing, has the athlete improved?

☐ Yes ☐ No ☐ Unsure ☐ Not Applicable

I am a physician or licensed healthcare professional and I have personally administered or supervised the administration of this SCAT5.

Signature: ____________________________

Name: ____________________________

Title: ____________________________

Registration number (if applicable): ____________________________

Date: ____________________________

**SCORING ON THE SCAT5 SHOULD NOT BE USED AS A STAND-ALONE METHOD TO DIAGNOSE CONCUSSION, MEASURE RECOVERY OR MAKE DECISIONS ABOUT AN ATHLETE’S READINESS TO RETURN TO COMPETITION AFTER CONCUSSION.**

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Appendix 4.

CLINICAL NOTES:

Name: __________________________
DOB: __________________________
Address: _______________________
ID number: _____________________
Examiner: ______________________
Date: __________________________

CONCUSSION INJURY ADVICE

(To be given to the person monitoring the concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. Recovery time is variable across individuals and the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, worsening headache, double vision or excessive drowsiness, please telephone your doctor or the nearest hospital emergency department immediately.

Other important points:

Initial rest: Limit physical activity to routine daily activities (avoid exercise, training, sports) and limit activities such as school, work, and screen time to a level that does not worsen symptoms.

1) Avoid alcohol

2) Avoid prescription or non-prescription drugs without medical supervision. Specifically:
   a) Avoid sleeping tablets
   b) Do not use aspirin, anti-inflammatory medication or stronger pain medications such as narcotics

3) Do not drive until cleared by a healthcare professional.

4) Return to play/sport requires clearance by a healthcare professional.

Clinic phone number: __________________________
Patient’s name: __________________________
Date / time of injury: _______________________
Date / time of medical review: ________________
Healthcare Provider: ________________________

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INSTRUCTIONS

Words in Italics throughout the SCAT5 are the instructions given to the athlete by the clinician.

Symptom Scale
The time frame for symptoms should be based on the type of test being administered. At baseline it is advantageous to assess how an athlete "typically" feels whereas during the acute/post-acute stage it is best to ask how the athlete feels at the time of testing.

The symptom scale should be completed by the athlete, not by the examiner. In situations where this ceiling is prominent, the examiner may wish to make the task more difficult by incorporating two 5-word groups for a total of 10 words per trial. In this case, the maximum score per trial is 10 with a total trial maximum of 30.

Immediate Memory
The Immediate Memory component can be completed using the traditional 5-word per trial list or, optionally, using 10-words per trial. The literature suggests that the Immediate Memory has a notable ceiling effect when a 5-word list is used. In settings where this ceiling is prominent, the examiner may wish to make the task more difficult by incorporating two 5-word groups for a total of 10 words per trial. In this case, the maximum score per trial is 10 with a total trial maximum of 30.

Choose one of the word lists (either 5 or 10). Then perform 3 trials of immediate memory using this list.

Complete all 3 trials regardless of score on previous trials.

"I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order. "The words must be read at a rate of one word per second.

Trials 2 & 3 MUST be completed regardless of score on trial 1 & 2.

Trials 2 & 3:
"I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before."

Score 1 pt. for each correct response. Total score equals sum across all 3 trials. Do NOT inform the athlete that delayed recall will be tested.

Concentration

Digits backward
Choose one column of digits from lists A, B, C, D, E or F and administer those digits as follows:

Say: "I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7."

Begin with first 3 digit string.

If correct, circle "Y" for correct and go to next string length. If incorrect, circle "N" for the first string length and read trial 2 in the same string length. One point possible for each string length. Stop after incorrect on both trials (2 Ns) in a string length. The digits should be read at the rate of one per second.

Months in reverse order
"Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November ... Go ahead"

1 pt. for entire sequence correct.

Delayed Recall
The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section.

"Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order."

Score 1 pt. for each correct response.

Modified Balance Error Scoring System (mBESS)® testing
This balance testing is based on a modified version of the Balance Error Scoring System (BESS)®. A timing device is required for this testing. Each of 20-second trial/stance is scored by counting the number of errors. The examiner will begin counting errors only after the athlete has assumed the proper start position. The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum number of errors for any single condition is 10. If the athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once the athlete is set. Athletes who are unable to maintain the testing procedure for a minimum of five seconds at the start are assigned the highest possible score, ten, for that testing condition.

OPTION: For further assessment, the same 3 stances can be performed on a surface of medium density foam (e.g., approximately 50cm x 40cm x 6cm).

Balance testing – types of errors
1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of test position > 5 sec

"I am now going to test your balance. Please take your shoes off (if applicable), roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty second tests with different stances."

(a) Double leg stance:
"The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. I will start timing when you are set and have closed your eyes."

(b) Single leg stance:
"If you were to kick a ball, which foot would you use? [This will be the dominant foot] Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

(c) Tandem stance:
"Now stand heel-to-toe with your non-dominant foot in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

Tandem Gait
Participants are instructed to stand with their feet together behind a starting line (the test is best done with footwear removed). Then, they walk in a forward direction as quickly and as accurately as possible along a 38mm wide (sports tape), 3 metre line with an alternate foot heel-to-toe gait ensuring that they approximate their heel and toe on each step. Once they cross the end of the 3m line, they turn 180 degrees and return to the starting point using the same gait. Athletes fail the test if they step off the line, have a separation between their heel and toe, or if they touch or grab the examiner or an object.

Finger to Nose
"I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended), pointing in front of you. When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose, and then return to the starting position, as quickly and as accurately as possible."

References
CONCUSSION INFORMATION

Any athlete suspected of having a concussion should be removed from play and seek medical evaluation.

Signs to watch for

Problems could arise over the first 24-48 hours. The athlete should not be left alone and must go to a hospital at once if they experience:

• Worsening headache
• Drowsiness or inability to be awakened
• Inability to recognize people or places

Consult your physician or licensed healthcare professional after a suspected concussion. Remember, it is better to be safe.

Rest & Rehabilitation

After a concussion, the athlete should have physical rest and relative cognitive rest for a few days to allow their symptoms to improve. In most cases, after no more than a few days of rest, the athlete should gradually increase their daily activity level as long as their symptoms do not worsen. Once the athlete is able to complete their usual daily activities without concussion-related symptoms, the second step of the return to play/sport progression can be started. The athlete should not return to play/sport until their concussion-related symptoms have resolved and the athlete has successfully returned to full school/learning activities.

When returning to play/sport, the athlete should follow a stepwise, medically managed exercise progression, with increasing amounts of exercise. For example:

**Graduated Return to Sport Strategy**

<table>
<thead>
<tr>
<th>Exercise step</th>
<th>Functional exercise at each step</th>
<th>Goal of each step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Symptom-limited activity</td>
<td>Daily activities that do not provoke symptoms.</td>
<td>Gradual reintroduction of work/school activities.</td>
</tr>
<tr>
<td>2. Light aerobic exercise</td>
<td>Walking or stationary cycling at slow to medium pace. No resistance training.</td>
<td>Increase heart rate.</td>
</tr>
<tr>
<td>4. Non-contact training drills</td>
<td>Harder training drills, e.g., passing drills. May start progressive resistance training.</td>
<td>Exercise, coordination, and increased thinking.</td>
</tr>
<tr>
<td>5. Full contact practice</td>
<td>Following medical clearance, participate in normal training activities.</td>
<td>Restore confidence and assess functional skills by coaching staff.</td>
</tr>
<tr>
<td>6. Return to play/sport</td>
<td>Normal game play.</td>
<td></td>
</tr>
</tbody>
</table>

In this example, it would be typical to have 24 hours (or longer) for each step of the progression. If any symptoms worsen while exercising, the athlete should go back to the previous step. Resistance training should be added only in the later stages (Stage 3 or 4 at the earliest).

**Written clearance should be provided by a healthcare professional before return to play/sport as directed by local laws and regulations.**

**Graduated Return to School Strategy**

Concussion may affect the ability to learn at school. The athlete may need to miss a few days of school after a concussion. When going back to school, some athletes may need to go back gradually and may need to have some changes made to their schedule so that concussion symptoms do not get worse. If a particular activity makes symptoms worse, then the athlete should stop that activity and rest until symptoms get better. To make sure that the athlete can get back to school without problems, it is important that the healthcare provider, parents, caregivers and teachers talk to each other so that everyone knows what the plan is for the athlete to go back to school.

Note: If mental activity does not cause any symptoms, the athlete may be able to skip step 2 and return to school part-time before doing school activities at home first.

<table>
<thead>
<tr>
<th>Mental Activity</th>
<th>Activity at each step</th>
<th>Goal of each step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Daily activities that do not give the athlete symptoms</td>
<td>Typical activities that the athlete does during the day as long as they do not increase symptoms (e.g., reading, texting, screen time). Start with 5-15 minutes at a time and gradually build up.</td>
<td>Gradual return to typical activities.</td>
</tr>
<tr>
<td>2. School activities</td>
<td>Homework, reading or other cognitive activities outside of the classroom.</td>
<td>Increase tolerance to cognitive work.</td>
</tr>
<tr>
<td>3. Return to school part-time</td>
<td>Gradual introduction of school work. May need to start with a partial school day or with increased breaks during the day.</td>
<td>Increase academic activities.</td>
</tr>
<tr>
<td>4. Return to school full-time</td>
<td>Gradually progress school activities until a full day can be tolerated.</td>
<td>Return to full academic activities and catch up on missed work.</td>
</tr>
</tbody>
</table>

If the athlete continues to have symptoms with mental activity, some other accommodations that can help with return to school may include:

• Starting school later, only going for half days, or going only to certain classes
• Taking lots of breaks during class, homework, tests
• No more than one exam/day
• Shorter assignments
• Repetition/memory cues
• Use of a student helper/tutor
• Reassurance from teachers that the child will be supported while getting better

The athlete should not go back to sports until they are back to school/learning, without symptoms getting significantly worse and no longer needing any changes to their schedule.
Concussion in the international ice hockey World Championships and Olympic Winter Games between 2006 and 2015

by

Tuominen M, Hänninen T., Parkkari J., Stuart MJ, Luoto T, Kannus P, Aubry M.

2017

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Concussion in the international ice hockey World Championships and Olympic Winter Games between 2006 and 2015

Markku Tuominen,1 Timo Hänninen,2 Jari Parkkari,2 Michael J Stuart,3 Teemu Luoto,4 Pekka Kannus,5 Mark Aubry6

ABSTRACT

Background Concussions in sports are a growing concern. This study describes the incidence, injury characteristics and time trends of concussions in international ice hockey.

Methods All concussions in the International Ice Hockey Federation (IIHF) World Championships (WC) and Olympic Winter Games were analysed over 9 ice hockey seasons between 2006 and 2015 using a standardised injury reporting system and diagnoses made by the team physicians.

Results A total of 3293 games were played (169 tournaments, 1212 teams, 26 130 players) comprising 142 244 athletic game exposures. The average injury rate (IR) for concussion was 1.1 per 1000 ice hockey player-games for all IIHF WC tournaments. The IR was the highest in the men’s WC A-pool tournaments and Olympic Games (IR 1.6). However, the annual IR for concussion in the men’s tournaments has been lower than that in the World Junior tournaments since 2012. When a concussion occurred with contact to a flexible board, the IR was 0.2 per 1000 player games. In contrast, the IR was 1.1, if the board and glass were traditional (for the latter, RR 6.44 (95% CI 1.50 to 27.61)). In the men’s tournaments, the trend of concussions caused by illegal hits decreased over the study period. After the 4th Consensus Statement on Concussion in Sport was published (2013), none of the concussed players in the men’s WC returned to play on the day of injury.

Conclusions The annual risk of concussion in the men’s WC has decreased during the study period. This was most likely due to a reduction in illegal hits. The risk of concussion was significantly lower if games were played on rinks with flexible boards and glass. Rink modifications, improved education and strict rule enforcement should be considered by policymakers in international ice hockey.

INTRODUCTION

Ice hockey is a collision sport executed on a hard ice surface surrounded by a perimeter of board and glass. Players reach high skating velocities and rapidly change direction. The fast-moving puck, swinging sticks and six players per team in a small space contributes to risk of concussion.1–8

The International Ice Hockey Federation (IIHF) is responsible for ice hockey at the Olympic Winter Games (Olympic Games) and coordinates the annual IIHF World Championships (WC) at all skill levels of men (WS), women (WW), juniors under-20 years (WJ U20), juniors under-18 years (WJ U18) and women under-18 years (WW U18). A total of 28 WC tournaments, 10 Olympic Qualification tournaments and a Youth Olympic tournament were held in collaboration with the local organising committees during the 2015–2016 season.

In all WC tournament games, the active playing time is three periods of 20 min each. The main difference between male and female ice hockey rules is that body checking is legal in the men’s game. Intentional body checking is not permitted in any level of women’s ice hockey.1–9 The equipment is similar for all ice hockey players, except facial protection. All female and male U18 players must wear full-facial protection (full cage or shield), but male players over 18-year of age are allowed to wear partial-facial protection (visor). In addition, mouth guard is mandatory in WJ U20 category for players wearing visor.10 The exact size of a hockey rink and its sections (offensive zone, neutral zone and defensive zone) varies among arenas but not between sex, age or levels of tournament.11 Modern rink materials have flexibility and the capacity to absorb the energy of players colliding with boards and perimeter glass; this has led to the gradual replacement of traditional rinks with modern flexible material.12

Concussion in sport is a clinical syndrome of traumatically induced transient disturbance of normal brain function. The lateral and temporal area of the head are the most common areas to be struck resulting in concussion. In ice hockey, concussion impacts are more likely to occur from contact with another body part or object rather than another head. Differences in mechanisms of injuries have been found between men and women.10 The diagnosis of concussion relies on a clinician’s evaluation. Injury mechanics, visible signs, reported symptoms, changes in cognitive and/or physical performance and exclusion of a more severe neurotrauma are the fundamentals of clinical assessment.16–20 The systematic collection of all ice hockey injuries shows that concussion is one of the most common injury type resulting to missed participation in both sexes.21–29 Furthermore, growing concerns on the possible lingering detrimental effects of concussion have addressed the need for preventive measures.30

We aimed to describe the incidence of concussions in international ice hockey. In addition, we examined and analysed possible contributing factors, including: (1) injury causes, (2) injury location on the ice, (3) the period of the game, (4)
player position and (5) contact with the board at the time of the incident. We also examined the differences in concussion rates stratified by sex, age groups and the level of play to help develop concussion recognition and prevention programmes at all levels of play.31

METHODS

During the nine ice hockey seasons between 2006–2007 and 2014–2015 (from 1 July 2006 to 30 June 2015), we registered, with the permission from the IIHF, all ice hockey injuries from the 169 ice hockey tournaments. Forty-four of them were World Senior Championships (WS) (10 of them were A-pool tournaments), two Olympic Winter Games (Olympic Games), and eight Olympic Qualification tournaments. Seventy tournaments were World Junior under-18 and under-20 Championships (WJ U18; WJ U20) (19 of them were A-pool tournaments). Forty-three tournaments were women’s World Championships (WW) (14 of them were A-pool tournaments) and two Olympic Games. Fifteen of the women’s World Championships were women’s under-18 tournaments (WW U18). A total of 3293 games were played in the 169 tournaments by 1212 teams (26 130 players) comprising 142 244 athletic game exposures.

Before each tournament, a team medical personnel meeting allowed the IIHF Medical Supervisor (MS) to review the definition of each injury, game injury report form (GIR) and the injury report system (IRS, figure 1) with the individual team physicians. The definition of an injury was made in accordance with the accepted international ice hockey norms. Minor injuries that allowed the athlete to continue playing and did not require medical attention were not included. An IRS form was completed when one of the following criteria was observed:

- any injury sustained in a practice or a game that prevented the player from returning to the same practice or game;
- any injury sustained in a practice or a game that caused the player to miss a subsequent practice or game;
- a laceration which required medical attention;
- all dental injuries;
- all concussions;
- all fractures.

The individual team physician followed all the players on their team and submitted the GIR form to the MS after each contest. The GIR form was used to verify the number of injuries that satisfied the definition (figure 2). The team physician was also required to complete a detailed injury report (IRS form) for every injury. The IRS form was returned to the MS during

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**Injury Report System/IRS**

*only one injury/form*

**Injury Definition**

The definition of an injury in the IIHF Injury Reporting System is as follows:

1. An injury is considered reportable if a player misses a practice or a game because of an injury sustained during a practice or a game.
2. The player doesn’t return to the play for the remainder of the game following an injury.
3. All fractures.
5. Any laceration which requires medical attention.
6. All fractures.

**Source of Diagnosis**

- Medical Doctor
- Physiotherapist
- Other

**Site / Body Part**

- Hit out a separate form for each injury
- 1. N/A
- 2. Left
- 3. Right
- 4. Both

- Head
- Shoulder
- Chest
- 28. Genitals
- Face
- 31. Scapula
- Abdomen
- 29. Hip
- Neck
- Upper arm
- 21. Kidneys
- 30. Thigh
- Throat
- 13. Elbow
- 32. Back
- 31. Knee
- 14. Forearm
- 33. Lower Back
- 32. Leg
- Teeth/Alveol
- 15. Wrist
- 24. Cervix
- 33. Ankle
- Eye
- 16. Hand
- 25. Buttocks
- 34. Foot
- Ear
- 17. Thumb
- 26. Paws
- 35. Toes
- Cervix
- 18. Fingers
- 27. Grains
- 36. Other

**Joint/Part**

- Mclamaged? Yes
- No
- Custom made? Yes
- No

**Knee**

Circle the appropriate structure involved:

1. ACL
2. PCL
3. MCL
4. LCL
5. Meniscus
6. MFL

**Shoulder**

Circle the appropriate structure involved:

1. AC
2. SC
3. Glenohumeral

**Grades**

1
2
3

**Game / Period**

1. Warm-up
2. 1st
3. 2nd
4. 3rd
5. 4th
6. Playing time

**Practice**

- 7. With Contact
- 8. No Contact

**Position**

- 1. Centre
- 2. Wing
- 3. Defence
- 4. Goalie
- 5. Forward
- 6. Player
- 7. Backward
- 8. Other

**Time Last:**

- 9. 1 Hour
- 10. More than 1 Hour

**Nature of Injury:**

- 1. Return same day
- 2. Less than 3 weeks
- 3. 3 to 6 weeks
- 4. More than 6 weeks

**Diagnosis:**

- 1. Full Face mask
- 2. Shoulder
- 3. Neck
- 4. Other

**Equipment:**

- 1. Full Face mask
- 2. Shoulder
- 3. Neck

**Figure 1** Injury report system form of the International Ice Hockey Federation.
the tournament as soon as all the sufficient information had been obtained and the final diagnosis was confirmed. The IIHF MS assigned to each championship was responsible for the data collection. The IRS form was filled out only once for each injury and included detailed information on the game period, ice location, mechanism, anatomic site, severity and specific injury diagnosis. The anonymous forms were returned to the IIHF Medical Committee for insertion into a computer-based IRS for ice hockey injuries (Medhockey, Medisport, Finland).

The injury rate (IR) was expressed as the number of injuries per 1000 ice hockey player-games and per 1000 player-game hours. These two different IR definitions were used to allow comparison with other ice hockey leagues, and other sports (rugby, football, basketball).32–35

The population-at-risk or player exposure to injury was determined by an estimation of the collective playing time. The number of player-games was based on 20–22 players competing for each team in a game depending on the specific level and year of a given tournament. Only the participating athletes were included in the denominator when calculating the incidence of injury.

The player-game IR was an average risk of injury for 1 individual player per 1000 games (# injuries/# players (2 teams)/# games×1000= injuries per 1000 player-games). The IR for 1000 player-game hours was based on a 60 min active game with five players and a goalie per team on the ice at the same time (# injuries/# players on ice same time (2 teams) / # games×1000= number of injuries per 1000 player-game hours).

Concussion was a clinical diagnosis made by a team physician. At the Team Medical Personnel Meeting, physicians were advised to follow the recommendations provided by the Consensus Statement on Concussion in Sport and were given

Figure 2  Game injury report form of the International Ice Hockey Federation.

IIHF Daily Injury Report Form

IIHF Championship: __________________________

National Association: __________________________

Date: ____________/__________/__________ (dd/mm/yy)

Using this form, please report if there were any injuries sustained by any player on your team during the above-mentioned day during this IIHF Championship. We would ask that you also report if there were no injuries sustained by players on your team during this day of this IIHF Championship. If an injury was sustained during this day then an IIHF Injury Report Form must be completed and submitted to the IIHF Medical Supervisor or, in his absence, to the IIHF Directorate Chairman providing the details of the injury sustained.

The definition of an injury used by the IIHF for reporting purposes is as follows:

1. An injury is considered reportable if a player misses a practice or a game because of an injury sustained during a practice or a game
2. The player does not return to the play for the remainder of the game following an injury
3. All concussions
4. All dental injuries
5. Any laceration which requires medical attention
6. All fractures

Please check (√) the appropriate box below. Please provide the number of injuries sustained if you check article 'A'.

Injury Report

A. During this day there were _____ injuries sustained by our team. (√)
   (number)

B. During this day there were no injuries sustained by our team

Team Physician/Medical Representative: __________________________

Signature: __________________________

Date: __________________________
the Sport Concussion Assessment Tool (SCAT) to use as a tool in making the clinical diagnosis.16–19 Concussions that occurred during practice were excluded because there were very few documented injuries (n=3, 2%); therefore, the given IRs in this study refer to game injuries only. Time loss was used as a proxy to determine the injury severity. The severity was graded into four groups by the team physician according to the IRS form (figure 1). Concussions caused by illegal contact were defined to checking to head (CTH), checking from behind, stick, fighting and body contact in female games. All other concussions were caused by legal reasons (figure 1).

The outcomes from A-pool tournaments are reported separately, because the tournaments represent the highest level of international championships in each age group. The injury results are presented as total numbers, percentages and rates (injuries per 1000 player-games and per 1000 player-game hours). Risk ratios (RRs) and 95% CIs for concussion were calculated by comparing traditional board and glass with flexible board and glass. RRs were also used to compare differences between the sexes. ORs and 95% CI were calculated to determine the association between player’s positions, groups, causes, the arena characteristics and concussions. ORs were calculated for the senior women’s WC and WW U18 tournaments separately.

RESULTS

Incidence of injury

Concussions accounted for 10% of all injuries in the championships, including 160 concussions reported in 3293 games. The average IR for concussion per 1000 ice hockey player-games was 1.1 for all IIHF WC. The annual IR ranged between 0.7 (2007) and 1.6 (2012). The results of the different groups can be found in table 1.

Annual IR for concussion

The time trend of concussions and annual IRs are shown in figure 3. The IR for concussion was highest in the men’s world Championships A-pool tournaments and Olympic Games. In the men’s tournaments, the IR for concussion decreased, especially in WS A-pool tournaments. The annual IR for concussion in the men’s tournament has been lower than that in the WJ tournaments since 2012. The trends of annual IRs for concussion in WJ U18 and WJ U20 tournaments were slowly increasing (figure 3). In the WW tournaments, no clear time trend was observed.

Contact with the boards

The majority of concussions occurred away from the boards (56%; IR 0.6). This trend was apparent in all championships and was similar over the nine-season study period with the exception of the seasons 2007–2009. In the WJ U20 A-pool tournaments, 72% (IR 1.0) and in WW U18 tournaments 67% (IR 0.9) of concussions occurred without board contact. IR for concussions that occurred with board contact was highest in the WS A-pool (IR 0.7) and WJ U18 (IR 0.7) A-pool tournaments.

Flexible board and glass

The men’s A-pool WC tournaments that were played in arenas with flexible board and glass had an overall concussion IR of 1.0 per 1000 player-games, when compared with 2.0 per 1000 player-games when traditional boards and glass were in place (for the latter, RR 2.07 (95% CI 1.06 to 4.04)). When concussion occurred with board contact, the IR was 0.2 per 1000 player games when flexible board and glass was used, compared with the IR 1.1 when traditional board and glass was used (for the latter, RR 6.44 (95% CI 1.50 to 27.61)). There were no differences between the IRs of concussions when the concussion occurred without board contact: traditional board and glass (IR 0.9) versus flexible board and glass (IR 0.8) (figure 4).

Causes of concussion

The most common situation leading to concussion was contact with another player (89%) (WS A-pool 91%). Concussions were caused mainly by a CTH (42%), body checking (23%), checking from behind (13%) and unintended collision (UC) (13%). Ninety per cent of the concussions caused by checking from behind occurred with contact to the board. The highest IR for concussion caused by CTH were in WJ U18 (56%) and WJ U20 A-pool (61%) tournaments (IR 0.8, respectively). In the WW tournaments, concussion was caused mainly by UC (34%); IR 0.3) and body checking (31%; IR 0.3). Fighting caused 3% of the concussions in all the tournaments and 7% in the WS A-pool tournaments (figure 5).

Sixty-six per cent of the concussions were caused by illegal contact. In all the tournaments, the trend of annual IR for concussion caused by illegal contact was slowly decreasing and the trend of annual concussion IR caused by legal reasons was slowly increasing. In the WS tournaments, the trend of the annual concussion rate caused by illegal contact was significantly decreasing, but the trend for legally caused concussion remained stable (figure 6). In the WJ tournaments, the trends of annual concussion rate caused by illegal or legal reasons were increasing (figure 7). Penalties were assessed in 31% of concussions. In 40% of concussion caused by CTH and in 50% of concussions caused by checking from behind, a penalty was called.

Injury severity

Nine per cent of the players who were diagnosed a concussion returned to play on the day of injury. In the WS tournaments, 14% of the concussed players returned to the same game (in the WS A-pool 8%) before the publication of the 2012 Zurich Consensus Statement (no return to play in the same game following a concussion).19 Following the 4th Consensus Statement on Concussion in Sport was published (2013), publication none of the concussed players in WS tournaments returned to the same game. However, in other tournaments, the percentage of return during the same day were similar before and after 2012 Zurich Consensus Statement.
Concussions were distributed according to player position: wing 37% (WS A-pool 41%) (two wings per team), centre 23% (WS A-pool 26%) (one centre per team) and defence 38% (WS A-pool 33%) (two defences per team). The goalkeeper was the least injured of all positions (1%). In the WS A-pool tournaments, 67% of concussions occurred among forwards and 33% among defence. The centre had the highest concussion rate in the WS A-pool tournaments (IR 0.4) and women’s tournaments (45%; IR 0.4). In the WJ U18 tournaments, wing (53%; IR 0.6; two wings per team) had the highest risk for concussion compared with the other positions.

There were no differences between the periods. Percentages of periods for concussed players were 33%, 31% and 31% during the games. Few concussions occurred during the warm up or overtime. In the WS A-pool games, 43% of the concussions occurred during the first period. The third period had the lowest IR. In the WJ U18 and WW tournaments, the lowest IR was during the first and the highest during the third period.

Players sustained concussions in the home zone (36%) (WS A-pool 41%), visitor zone (37%) (WS A-pool 35%) and neutral zone (23%) (WS A-pool 24%). In the WJ U20 A-pool tournaments, 28% of the concussions occurred in the neutral zone.

Concussion rate for men was higher than women, but the results were statistically non-significant (RR 1.29 (95% CI 0.87 to 1.91)). Results related to the player’s position, cause of concussion and the arena characteristics are summarised in Table 2.
DISCUSSION

Our prospective, observational study from 2006 to 2015 monitored 169 ice hockey World Championship tournaments and Olympic Games over 9 ice hockey seasons to determine the incidence and circumstances of concussion. The diagnosis accounted for 10% of all injuries in the championships, including 160 concussions in 26,130 players who competed in 3,293 games. The concussion rate was 1.1 per 1000 ice hockey player-games and 4.0 per 1000 player-game hours. The highest concussion rate was in the WS tournaments (IR 1.2) and lowest in the WW tournaments (IR 0.9).

World senior A-pool tournaments results compared with the NHL studies

The injury risk for concussions in WS A-pool tournaments was similar to the National Hockey League (NHL). Benson et al. estimated the incidence of concussions in NHL as 1.8 per 1000 player-game hours, where the athlete-exposure time was estimated based on a roster of 18 skaters and 1 goalie playing in each team per game. The proportion of concussions sustained by a centre was about twice that of defencemen and wingers. In our study, WS A-pool tournaments had a similar injury risk for concussion (IR 1.6) and the centre was the most injured position.

Hutchison et al. used systematic video analysis of NHL to report that 88% of concussions occurred due to contact with an opponent and 5% involved contact with a teammate. Eight per cent of concussions were due to fighting, although the incidence for this mechanism may be underestimated due to detection bias. Sixty-five per cent of the concussions were sustained by forwards, 32% by defencemen and 3% by goalies. The majority of the concussions occurred in the first period (47%). Concussions were distributed relatively equally in the second,

Figure 5 Injury rates per 1000 player-games for causes of concussions.

Figure 6 Annual injury rate per 1000 player-games for concussion in the World Senior Championships tournaments caused by legal or illegal hit.
(27.9%) and third (25.1%) periods. Forty-five per cent of concussions occurred in the defensive zone, 34% in the offensive zone and 21% in the neutral zone. The most common body part initially contacted by the hitter was the player’s head (68%) with 22% of direct head contact from the shoulder, elbow or gloves. A penalty was called 29% of cases of concussions. The present findings from WS A-pool tournaments support the NHL findings by Hutchison et al.37 38

The IIHF and the NHL should work together to identifying common mechanisms and institute rules that will help prevent concussions. All hits to the head, whether intentional or unintentional, should be penalised consistent with recent rule changes by Hockey Canada and USA Hockey.

Changes in the annual risk of concussion
Concussion risk in World Senior tournaments has decreased and since 2012, the annual risk of concussion in those tournaments has been lower than that in World Junior tournaments. The concussion rate resulting from illegal hits decreased in the World Senior tournaments but has slowly increased in other tournaments. More attention is needed to decrease the concussion risk in World Junior tournaments caused by illegal hits. Further studies are needed to clarify the effect of improved rule enforcement, disciplinary panel suspensions, player education and attitude on reducing the risk of concussion.

Differences between periods, positions and sex
Most of the concussions at the men’s highest level of competition occurred during the first period, when the players are maximally energised and able to apply more force with greater acceleration to contacts. This finding is contrary to the risk analysis in the WJ U18 and women tournaments in which the risk for concussion was least in the first period and highest in the third period when players are expected to be more tired. There may be also an increase in intensity in the third period because of its importance in determining the outcome of the game.

In the WW U18 tournaments, the centre had a statistically significant higher risk for concussion compared with the other positions and most of concussions were caused by body checking or a UC. These results may reflect the fact that girls do not have enough strength and awareness to avoid collisions and are not physically able to withstand a collision. Female sex has been associated with a higher risk of sport-related concussions.39 11

Our study identifies a higher risk of concussion in men, but the result was not statistically significant.

Effect of flexible board and glass
More flexible rink materials and protective installation methods improve impact energy resorption, resulting in lower peak forces and greater stopping distances. These should decrease the risk of concussions.39 15 11 This study is the first to report that the risk of concussion is lower when flexible boards and glass are in use. Installation of flexible board and glass is highly recommended to decrease the risk of concussion and shoulder injuries in all future tournaments, especially in WS and WJ U18 tournaments, where the IRs for shoulder injuries and concussions occurred contact with board were highest.27 29

Return to game on the day of injury
None of the concussed players since 2012 returned to the same game in the WS tournaments in keeping with the 4th Consensus Statement on Concussion in Sport (2013).19 Conversely, the policy of returning to competition on the day of injury has not changed in other tournaments.19 We recommend more thorough education on concussion management and effective injury prevention measures are especially needed for the WJ and WW tournaments.

Strengths and limitations
The strengths of this study include the large number of players competing at each age groups’ highest international level over a nine-season period. All the injuries were systematically collected and the number of injury events was determined with an accepted injury definition that incorporated a specific diagnosis, standardised nomenclature, a reliable data collection instrument and time lost from play.31 The detailed information was
The limitations of the study were that injuries were analysed in tournament games only and not in practice or training. The injury reporting system relied on the individual team physician to record the mechanism and type of injury. A more accurate description of the injury mechanisms would require a detailed review of the multiangle game videos. A more consistent and detailed injury diagnosis would require examination of every injured athlete at each tournament by a single experienced physician in concussion. Injury incidence rates were estimated by collective playing time since individual on-ice exposure could not be feasibly measured. We assumed that six players were on the ice for each team during the 60 min game. Thus, this method did not take penalties, overtime or time-lost injuries during a game into consideration. The severity of the injury was also based on an estimate of the time to return to play written by the team physician.

What are the findings?

▸ The overall concussion rate in the International Ice Hockey Federation World Championships and Olympic Winter Games was on average 1.1 per 1000 ice hockey player-games and 4.0 per 1000 player-game hours. The overall risk of concussion was highest in the men’s tournaments. However, the concussion rate in the men’s tournaments has been decreasing over the 9-year period and since 2012, annual risk of concussion in the men’s tournaments has been lower than in the junior tournaments.

▸ The concussion rate caused by illegal hits has been decreasing in the men’s tournaments but slowly increasing in the other tournaments.

▸ After the 4th Consensus Statement on Concussion in Sport was published (2013), none of the concussed players returned to play on the day of injury in the men’s tournaments. In other tournaments, the conclusions from the Consensus Statement have not been followed as players have returned to play on the day of injury. As this paper goes to press, the 5th Consensus Statement on Concussion in Sport is being finalised (2017 publication, Br J Sports Med).

▸ The risk of concussion was significantly lower when the game was played on an ice rink with a flexible board and glass.

▸ Flexible boards and glass should be used in ice hockey to help prevent concussions.

▸ Enforcing the existing rules, including head checks and checking from behind, may decrease the risk of concussion.

▸ More effective prevention strategies for concussions are needed, especially in junior and women’s ice hockey tournaments.

▸ Improved education of players, officials, coaches and physicians may mitigate concussion risk.

Table 2

<table>
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<tr>
<th>Variables</th>
<th>Category</th>
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<th>95% CI</th>
<th>OR</th>
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<td>5.04</td>
<td>(2.82 to 9.02)</td>
</tr>
<tr>
<td></td>
<td>Checking</td>
<td>1.28</td>
<td>(0.65 to 2.49)</td>
<td>1.26</td>
<td>(0.57 to 2.40)</td>
<td>0.68</td>
<td>(0.22 to 2.03)</td>
<td>1.62</td>
<td>(0.67 to 3.92)</td>
<td>0.58</td>
<td>(0.08 to 4.48)</td>
<td>0.24</td>
<td>(0.01 to 4.00)</td>
<td>1.28</td>
<td>(0.65 to 2.49)</td>
<td>1.26</td>
<td>(0.57 to 2.40)</td>
<td>0.68</td>
<td>(0.22 to 2.03)</td>
<td>1.62</td>
<td>(0.67 to 3.92)</td>
<td>0.58</td>
<td>(0.08 to 4.48)</td>
<td>0.24</td>
<td>(0.01 to 4.00)</td>
<td>1.28</td>
<td>(0.65 to 2.49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>with board contact</td>
<td>1.59</td>
<td>(0.85 to 2.97)</td>
<td>1.96</td>
<td>(0.98 to 3.93)</td>
<td>2.94</td>
<td>(1.41 to 6.13)</td>
<td>1.30</td>
<td>(0.50 to 3.36)</td>
<td>2.11</td>
<td>(0.58 to 7.63)</td>
<td>5.35</td>
<td>(1.87 to 15.29)</td>
<td>1.59</td>
<td>(0.85 to 2.97)</td>
<td>1.96</td>
<td>(0.98 to 3.93)</td>
<td>2.94</td>
<td>(1.41 to 6.13)</td>
<td>1.30</td>
<td>(0.50 to 3.36)</td>
<td>2.11</td>
<td>(0.58 to 7.63)</td>
<td>5.35</td>
<td>(1.87 to 15.29)</td>
<td>1.59</td>
<td>(0.85 to 2.97)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Statistically significant results are indicated in bold. *WW and WW U18 results are calculated separately.

CTH, check to the head.
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II

Sport Concussion Assessment Tool – 3rd edition – normative reference values for professional ice hockey players

by

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Original research

Sport concussion assessment tool – 3rd edition – normative reference values for professional ice hockey players

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A R T I C L E   I N F O

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Clinical assessment

A B S T R A C T

Objectives: To determine normative reference values for the Sport Concussion Assessment Tool—3rd Edition (SCAT3) using a large sample of professional male ice hockey players.

Design: A descriptive cross-sectional study.

Methods: Preseason baseline testing was administered individually to 304 professional male ice hockey players.

Results: The participants were aged between 16 and 40 with a mean (M) age of 25.3 years. Over 60% of the athletes reported previous concussion, almost 20% had been hospitalized or medically imaged following a head trauma. Of the players, 48% reported no symptoms. The symptom score median (Md) was 1.0 (Md = 1.5) and severity median was 1.0 (Md = 2.3). The median of the SAC score was 27.0 (Md = 27.0). The median of the M-BESS was 1.0 (Md = 2.0). The tandem gait median was 10.9 s (Md = 10.8 s). The most common baseline symptom was neck pain (24%). Delayed recall was the most difficult component of the SAC (Md = 4); only 24% performed it flawlessly. All athletes completed the double-leg stance of the M-BESS without errors, but there was performance variability in the tandem stance (Md = 0, M = 0.6, range = 0–10) and single-leg stance (Md = 1.0, M = 1.4, range = 0–10).

Conclusions: Representative normative reference values for the SCAT3 among professional male ice hockey players are provided.

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1. Introduction

Concussion is a common injury in ice hockey causing game and practice time loss. According to epidemiological studies on ice hockey players, the number of concussion per 1000 athlete exposures varies between 0.5 and 21.5 1–3 depending on the studied population and the method used to identify injuries. In general, the risk of concussion is greater during games than during practice (0.2–6.5/1000 game-hours compared with 0.1/1000 practice-hours). 2,4 The incidence of concussions in relation to the overall number of injuries is higher in the North American leagues compared to the European leagues.2

The Sport Concussion Assessment Tool—Third Edition (SCAT3) was published following the 4th International Conference on Concussion in Sport held in Zurich in November 2012.7 The SCAT3 supersedes the original SCAT and the SCAT2.6,7 It can be considered the current standard in the sideline assessment of sport-related concussion. It combines background information with objective assessment instruments aimed at capturing a spectrum of clinical signs and symptoms, cognitive dysfunction, and physical deficits of concussion. The SCAT3 can be deconstructed into nine individual sections: (i) potential signs of concussion cover the classic operational criteria of traumatic brain injury (e.g., loss of consciousness and amnesia); (ii) Glasgow Coma Scale is recorded in case of
neurological deterioration and exclusion of more severe brain injury; (iii) sport-specific orientation and amnesia is assessed using the five Maddocks questions; (iv) demographic variables, self-reported concussion history, potential outcome modifiers, and medications are collected in the background section; (v) the symptom evaluation consists of 22 symptoms that are graded on a dimensional scale from 0 (none) to 6 (severe). The symptom scale has been shown to be useful for the assessment of both symptom presence and severity.8 (vi) the cognitive assessment is based on the standardized assessment of concussion (SAC)9 and it consists of time orientation, immediate memory, concentration, and delayed recall; (vii) Neck examination; (viii) postural stability is assessed with the modified version of the balance error scoring system (M-BESS)10 and/or Tandem gait; and (ix) coordination is evaluated using the finger-to-nose (FTN) task.

The SCAT3 is widely used for assessing the acute effects of concussion. Post-injury SCAT3 scores are best interpreted in the context of what is normal for an individual athlete.11–13 This can be accomplished by comparing post-concussion performance with either an accurate and reliable individual baseline or to age- and sport-specific normative data.14 In professional contact sports, baseline testing with the SCAT3 is common. Even though individual baseline data is often available, normative values for the examined population are essential for better understanding of normal variation.

The different components [subjective: symptom score and severity; objective: SAC, coordination, M-BESS, and Tandem gait] of the SCAT3 have been individually investigated in a number of settings, but to date we found no previous studies examining the SCAT3 as a whole among professional male ice hockey players. The purpose of this study is to establish normative reference data for the SCAT3 using a large sample of professional male ice hockey players. We also aimed to describe possible background factors that might be related to SCAT3 scores and the associations between SCAT3 components.

2. Methods

This study is a part of a larger research project that strives to translate international recommendations regarding diagnosis and management of concussions into practice in Finnish professional ice hockey. Ethics approval for the study was obtained from the Ethical Committee of Pirkanmaa Hospital District, Tampere, Finland (code: R13070), and each participating athlete signed written informed consent according to the Declaration of Helsinki. This study was financially supported by the Finnish Ministry of Education and Culture; and the Finnish Hockey League. There was no involvement with any commercial sponsor for this study regarding: study design; the collection, analysis, and interpretation of data; the writing of the report; or the decision to submit the paper for publication.

The SCAT3 preseason baseline testing became mandatory for all players in the highest Finnish professional male ice hockey league before the 2013–2014 season. The league has 14 teams. The total number of players playing in the league was 427. The number of players participating in the study was 304 (71.2%). Most of the players who did not take part in the study were already baseline tested before season 2012–2013. Only the SCAT3 baseline tests administered for season 2013–2014 were included in this study. Other players were not included for various reasons (e.g., injuries or being sent down to another team).

Demographic variables and injury history were obtained at the time of testing using the background information section of the SCAT3. The SCAT3 was administered individually to every player before or after team practice. Testing was performed in one session at least 10 min after physical exertion, as recommended.13 One test took about 15–20 min. The testing was conducted by the team physiotherapist or physician (n = 22); they were trained to administer the SCAT3 in accordance with the SCAT3 instructions in regional training sessions led by the authors. If a player had sustained a concussion within the few months prior to testing, the player had to have been asymptomatic and participated at least one month in normal game play after the concussion and before the SCAT3 baseline was administered. A small subgroup did not speak Finnish or English as natives. This subgroup (total n = 19) was excluded from the statistical analyses of the symptom evaluation and the SAC components. Also, if the score of some subcomponent of the SCAT3 was incompletely filled or the scores were unreadable, the subject was excluded from the analyses of this subcomponent.

The translation of the SCAT3 from English into Finnish was accomplished by a professional translator. The aim of the translation was not to achieve literal or syntactical equivalence, but to maintain the original denotation and connotation of items. The Finnish version of the SCAT2 has been previously used in an emergency department setting.15 The SCAT3 contains the components of the SCAT2 and includes some additional components (e.g., Tandem gait). To illustrate the use of the normative data, SCAT3 results from three athletes who were assessed within 3 h of sustaining a concussion are presented in Section 4.

Descriptive statistics for the SCAT3 components were calculated [mean (M), median (Md), standard deviation (SD), interquartile range (IQR), and range]. The normative ranges for each SCAT3 variable were determined. Cutoffs were selected based on conventions commonly used in cognitive assessment (e.g., Wechsler classifications), and they were based on the natural distributions because SCAT3 scores are not normally distributed. The goal was to select a below/above average cutoff that corresponded with the 25th and 75th percentile ranks, but this usually was not possible given the score distributions. Unusually low/high scores correspond with approximately the 10th and 90th percentile ranks, and extremely low/high scores correspond with approximately the 2nd and 98th percentile ranks. The classifications were worded differently based on the direction of the scoring for the SCAT3 component. Symptom scores and number of errors on the M-BESS are referred to as high and performance on cognitive testing and Tandem gait are referred to as low.

Categorical background variables included: (i) history of concussions (0 versus ≥1); (ii) past hospitalization or medical imaging following head trauma, (iii) history of headache or migraine, (iv) history of developmental learning or attention problems, and (v) history of psychiatric problems. Continuous variables consisted of (i) age, (ii) years of education, (iii) number of past concussions, and (iv) time of recovery after the last concussion. The data related to neurodevelopmental history [i.e., history of learning or attention problems (n = 5; 1.7%) and history of psychiatric problems (n = 5; 1.7%)] could not be meaningfully analyzed due to small sample sizes. The normality of the variable distributions was tested using the Kolmogorov–Smirnov and Shapiro–Wilk tests. Continuous variables were analyzed with Spearman (nonparametric) correlation coefficients. Categorical variables in relation to continuous variables were tested with the Mann–Whitney U-test. Associations between categorical variables were examined using Pearson chi2 tests. The level of statistical significance was set at 0.05. Additionally, Cohen’s d-values (d) were calculated. IBM SPSS Statistics 20.0 (IBM Corp. Armonk, NY, USA) was used to perform the analyses.

3. Results

The athletes were aged between 16 to 40 years (M = 25.3 years, SD = 5.2), and 86.8% of the players were Finnish. All were Caucasian.
Table 1
Summary of the results of the SCAT3 components.

<table>
<thead>
<tr>
<th>Component</th>
<th>Scale</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Md</th>
<th>IQR</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptom score</td>
<td>0–22 Points</td>
<td>284</td>
<td>1.5</td>
<td>2.7</td>
<td>1.0</td>
<td>0–2–0</td>
<td>0–210</td>
</tr>
<tr>
<td>Symptom severity</td>
<td>0–132 Points</td>
<td>284</td>
<td>2.3</td>
<td>5.2</td>
<td>1.0</td>
<td>0–3–0</td>
<td>0–610</td>
</tr>
<tr>
<td>Standardized assessment of concussion</td>
<td>0–30 Points</td>
<td>279</td>
<td>27.0</td>
<td>1.7</td>
<td>7.0</td>
<td>25–0–28.0</td>
<td>19.0–30.0</td>
</tr>
<tr>
<td>Orientation</td>
<td>0–5 Points</td>
<td>282</td>
<td>4.9</td>
<td>0.3</td>
<td>5.0</td>
<td>0–5–5</td>
<td>3.0–5.0</td>
</tr>
<tr>
<td>Immediate memory</td>
<td>0–15 Points</td>
<td>284</td>
<td>14.6</td>
<td>0.6</td>
<td>15.0</td>
<td>14–0–15.0</td>
<td>12.0–15.0</td>
</tr>
<tr>
<td>Concentration</td>
<td>0–5 Points</td>
<td>282</td>
<td>3.9</td>
<td>0.9</td>
<td>4.0</td>
<td>3–0–5</td>
<td>2.0–5.0</td>
</tr>
<tr>
<td>Digits backward</td>
<td>0–4 Points</td>
<td>285</td>
<td>2.9</td>
<td>0.8</td>
<td>3.0</td>
<td>2–0–4</td>
<td>1.0–4.0</td>
</tr>
<tr>
<td>Delayed recall</td>
<td>0–5 Points</td>
<td>285</td>
<td>3.7</td>
<td>1.1</td>
<td>4.0</td>
<td>3–0–4</td>
<td>0–5.0</td>
</tr>
<tr>
<td>Coordination score</td>
<td>0–1 Points</td>
<td>299</td>
<td>1.0</td>
<td>0.1</td>
<td>1.0</td>
<td>1–0–1</td>
<td>0–1–0</td>
</tr>
<tr>
<td>M–BEss</td>
<td>0–30 Errors</td>
<td>295</td>
<td>2.0</td>
<td>2.5</td>
<td>1.0</td>
<td>0–2–0</td>
<td>0–20.0</td>
</tr>
<tr>
<td>Double leg stance</td>
<td>0–10 Errors</td>
<td>299</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0–0–0</td>
<td>0</td>
</tr>
<tr>
<td>Single leg stance</td>
<td>0–10 Errors</td>
<td>301</td>
<td>1.4</td>
<td>1.8</td>
<td>1.0</td>
<td>0–2–0</td>
<td>0–10.0</td>
</tr>
<tr>
<td>Tandem stance</td>
<td>0–10 Errors</td>
<td>296</td>
<td>0.6</td>
<td>1.5</td>
<td>0</td>
<td>0–0–0</td>
<td>0–10.0</td>
</tr>
<tr>
<td>Tandem gait (s)</td>
<td>Seconds</td>
<td>94‡</td>
<td>10.8</td>
<td>1.8</td>
<td>10.9</td>
<td>9.6–12.1</td>
<td>6.7–14.3</td>
</tr>
</tbody>
</table>

*As guided in the SCAT3 form, the teams had a chance to select the test used for postural stability. Testing with both the M-BESS and the Tandem gait was encouraged, but most players were not administered Tandem gait. Athletes who did not speak Finnish or English were not included in the symptom scores or the standardized assessment of concussion.

The SCAT3 was performed in English with 39 (12.8%) athletes; all others used the Finnish version. Nineteen (6.3%) participants were non-Finnish and non-English speakers. The average amount of education was 12.5 (SD = 1.9, range 7–18) years. Of the participants, 60.1% (n = 181) reported one or more previous concussions. The average number of concussions sustained prior to testing was 1.2 (Md = 1, SD = 1.4, IQR = 0 to 2, range = 0–12) and the median estimated time to recover after the last concussion was 7 days (M = 19.7, SD = 48.4, IQR = 6 to 14, range = 0–547). A minority (n = 59, 19.5%) had been hospitalized or undergone neuroimaging following head trauma. A small percentage reported a history of a neurodevelopmental problem (n = 5, 1.7%) or psychiatric problems (n = 5, 1.7%).

Baseline results for the SCAT3 components are presented in Table 1. The individual frequency distributions and associated normative classification ranges for the SCAT3 subscores are presented in Table 2. The distributions of the individual symptoms reported on the 22-item symptom scale are shown in Fig. 1. The most commonly endorsed baseline symptoms on the symptom Scale were: neck pain (n = 67, 23.5%), fatigue or low energy (n = 72, 21.8%), trouble falling asleep (n = 46, 16.2%), drowsiness (n = 42, 14.8%) and...

Table 2
Cutoff scores and classification ranges for the SCAT3 components for healthy professional male ice hockey players.

<table>
<thead>
<tr>
<th>Component</th>
<th>Broadly normal</th>
<th>Below average/above average</th>
<th>Unusually low/unusually high</th>
<th>Extremely low/extremely high</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cutoff</td>
<td>% In this range</td>
<td>Cutoff</td>
<td>% At or below</td>
</tr>
<tr>
<td>Symptom score (0–22p)</td>
<td>0–2</td>
<td>80.3</td>
<td>3</td>
<td>19.7</td>
</tr>
<tr>
<td>Symptom severity (0–132p)</td>
<td>0–3</td>
<td>82.7</td>
<td>4–5</td>
<td>17.3</td>
</tr>
<tr>
<td>Standardized assessment of concussion (0–30p)</td>
<td>26–30</td>
<td>83.5</td>
<td>25</td>
<td>16.5</td>
</tr>
<tr>
<td>Orientation (0–5p)</td>
<td>5</td>
<td>92.2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Immediate memory (0–15p)</td>
<td>14–15</td>
<td>93.7</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Concentration (0–5p)</td>
<td>3–5</td>
<td>95.7</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Digits backward (0–4p)</td>
<td>3–4</td>
<td>97.5</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Delayed recall (0–5p)</td>
<td>3–5</td>
<td>88.1</td>
<td>2</td>
<td>11.9</td>
</tr>
<tr>
<td>M–BEss (0–30 errors)</td>
<td>0–3</td>
<td>83.6</td>
<td>4–5</td>
<td>16.6</td>
</tr>
<tr>
<td>Single leg stance (0–10 errors)</td>
<td>0–2</td>
<td>82.4</td>
<td>3</td>
<td>17.6</td>
</tr>
<tr>
<td>Tandem stance (0–10 errors)</td>
<td>0–1</td>
<td>90.9</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Tandem gait (s)</td>
<td>12.1</td>
<td>76.6</td>
<td>12.2–12.8</td>
<td>23.4</td>
</tr>
</tbody>
</table>

Classification ranges are based on the natural distribution of scores because the distributions were not normal. The goal was to select a below/above average cutoff that corresponded with the 25th and 75th percentile ranks, but this usually was not possible given the score distributions. Unusually low/high scores correspond with approximately the 10th and 90th percentile ranks, and extremely low/high scores correspond with approximately the 2nd and 98th percentile ranks. The classifications are worded differently based on the direction of the scoring for the SCAT3 component. Symptom scores and number of errors on the M-BESS are referred to as high and performance on cognitive testing and tandem gait are referred to as low. The months in reverse were stated correctly by 94.0% (n = 265; not included as a row in Tables 1 or 2).
headache (n = 25, 8.8%); 48% reported no symptoms. On the SAC, only 24.2% (n = 69) obtained a perfect score on the delayed recall component. Similarly, digits backward was perfectly completed by 27.7% (n = 79). The months in reverse were stated correctly by 94.0% (n = 265). All athletes were able to complete the double-leg stance of the M-BESS, but there was variability in errors in the tandem stance (M = 0.6, Md = 0, SD = 1.5, range = 0–10) and the single-leg stance (M = 1.4, Md = 1.0, SD = 1.8, range = 0–10). The average time for the Tandem gait was 10.8 s. Only one participant couldn’t perform the Tandem gait in 14 s. The Spearman correlation between the M-BESS and Tandem gait was not significant (r = −0.06, p = 0.6). The only statistically significant correlation between the SCAT3 components was between the SAC and the Tandem gait (r = −0.25, p = 0.02), illustrating a small association between these measures.

The total scores of the SCAT3 components: symptom score/severity, SAC, M-BESS, Tandem gait, and coordination had no statistically significant (p > 0.05 in all analyses) association with age, years of education, history or number of past concussions, history of headache or migraine, or recovery time after the last concussion. Worse Symptom scores were related to past hospitalization or neuroimaging following head trauma (M = 2.4, SD = 4.0 versus M = 1.3, SD = 2.2; Mann–Whitney U = 5256.0, p = 0.015, d = 0.5), SAC, M-BESS, and coordination scores were unrelated to past hospitalization or neuroimaging following head trauma. Better Tandem gait performance was marginally associated with past hospitalization or neuroimaging following head trauma (M = 9.9, SD = 2.0 versus M = 11.0, SD = 1.6; Mann–Whitney U = 486.0, p = 0.045, d = 0.6), but not with number of previous concussions, or years of education.

4. Discussion

The symptoms listed on the SCAT3 are not specific to concussion. These symptoms are relatively common in non-concussed individuals, and more common in people with clinical conditions (e.g., migraine, anxiety disorders, depression, and bodily injuries). A recent literature review shows that 50–84% of high-school athletes reported these concussion-like symptoms at baseline. Similarly, 52% of athletes in our sample reported at least one post-concussion-like symptom. The average number of symptoms reported (M = 1.5) in our study was similar with the recent report by Echlin and colleagues (M = 1.6–3.1). In contrast, the average number of symptoms has been greater (up to 5.3 symptoms) in adolescent male athlete samples. In our study, the five most common baseline symptoms (neck pain, fatigue or low energy, trouble falling asleep, drowsiness, and headache) were similar to previous findings with young hockey players. Neck pain was the most common baseline symptom among our adult cohort, whereas fatigue or low energy has been the most prominent symptom reported by young players. The high prevalence of neck pain might be important because preseason reports of neck pain might be a risk factor for concussions.

Athletes with a self-reported previous history of concussion often report more symptoms at baseline than those without a concussion history. Headache is reported to be the most prominent symptom among young athletes who have been concussed in the past. In our study, the total number and severity of symptoms endorsed did not differ significantly between those who reported at least one previous concussion (56% endorsed one or more baseline symptoms) and those who did not (46% endorsed one or more baseline symptoms). However, worse Symptom scores were related to past hospitalization or neuroimaging following a head trauma. Those with a past hospitalization or neuroimaging following head trauma endorsed, on average, 2.4 symptoms (SD = 4.0) compared to those without this history endorsing on average 1.3 symptoms (SD = 2.2). Based on the current results and previous reports, we recommend that a post-injury Symptom Score of 4 or greater (occurring in 9.9% of the present sample; unusually high in Table 2), and/or a Symptom Severity of 6 or greater (occurring in 9.5% of the present sample; unusually high in Table 2) be considered unusual among professional male ice hockey players. Neck pain is included in the symptom scale and it was the most frequently endorsed symptom at baseline. It is important to appreciate when examining an athlete following a concussion that his symptoms might be partially related to other factors, such as a neck injury or stress.

In the present study, the normative values for the SAC and its subcomponents among adult professional ice hockey players seem to be similar to previous reports with other athletes. SAC
performance was not related to the background factors assessed in the SCAT3. Based on our results and previous studies, we recommend that a post-injury SAC score of 24 points or lower (occurred in 8.6% of the present sample; see Table 2) should be considered unusually low among adult male ice hockey players. The performance on the M-BESS in our sample was similar to the professional hockey players and young adult athletes examined in previous studies. Most errors were made in the single leg stance and none of the athletes made errors in double leg stance.\(^{10,18,26}\) When compared to normative data in a civilian sample, adult professional hockey players performed in a similar way to men aged 20-29 years.\(^{27}\) The M-BESS scores were not related to the SCAT3 background factors. Among adult male ice hockey players, we recommend that 6 or more errors on a post-injury M-BESS (occurred in 5.7% of the present sample; unusually high in Table 2) should be considered abnormal. The average time on the Tandem gait was similar to normative values reported for healthy people aged 16-37 years.\(^{20}\) Only one player out of 94 did not complete the test within 14 s. The best performance on the Tandem gait was a time of 6.7 s, and 90% of the sample completed the test in 12.8 or fewer seconds. More research is needed on the best post-concussion cut-off times for the Tandem gait. The Tandem gait and M-BESS scores were not related to one another. This suggests that these two tests measure different aspects of balance and postural stability. Also, it should be noted that the Tandem gait test is repeated four times in the SCAT3 and the best time is reported, whereas the M-BESS is performed only once. A possible learning effect on the Tandem gait cannot be excluded. There was a counterintuitive result that past hospitalization or medical imaging following head trauma was associated with better baseline performance on the tandem gait. However, the actual time difference between the tested subgroups was only 1 s (\(M = 9.9\) versus \(M = 11.0\), \(p = 0.045\)) and it is possible that the difference is spurious; therefore, the clinical significance of this finding can be considered minor.

Normative time values for the coordination (finger-to-nose test, FTN) have been documented by Schneiders et al. (\(M = 2.9\) s, SD = 1) and Sweine et al. (\(M = 3.4-3.6\) s, SD = 1).\(^{20,28}\) In the SCAT3, the FTN task is scored dichotomously (0 or 1 point). In the present study, three players out of 285 (1.1%) failed the test (scored 0) and could not perform five correct repetitions under four seconds. The results are similar to previous findings among young athletes.\(^{14,24}\) In general, a post-injury score of 0 on the FTN test warrants more thorough evaluation.

To illustrate the use of the normative reference values in Table 2, three cases are presented. Each person was evaluated within 3 h of sustaining a concussion. The first player was rendered unconscious on the ice and had significant balance problems while leaving the ice. On the SCAT3, approximately 2 h after being injured, he endorsed a heavy burden of symptoms (score = 14, severity = 50), his cognition was broadly normal (SAC = 27), his balance was abnormal (30 error points on the M-BESS; extremely high classification range), and his Coordination score was abnormal. For this athlete, baseline testing is not necessary to appreciate that he was seriously adversely affected by the concussion (although for completeness we note that his individual baseline SAC score was 26 and M-BESS score was 2). The second player took a blow to the head, he was not rendered unconscious, but he had a blank and vacant look in his eyes and he had some amnesia following the injury. On the SCAT3, approximately 2 h after his injury, he reported 11 symptoms of mostly mild severity (severity = 15), his cognitive functioning was in the extremely low classification range (SAC = 23), he passed the coordination exam, and his balance was broadly normal (M-BESS = 2). For this athlete, baseline testing is not necessary to appreciate that he was adversely affected by the concussion (individual baseline SAC score was 27 and M-BESS score was 0). Baseline testing, in his case, might be somewhat helpful in gauging his recovery on the SCAT3 in that a return to 27 points or greater on the SAC, and a return to perfect performance on the M-BESS (in addition to symptom recovery), is expected before proceeding through the return to play protocol. The third player took a blow to the head but it was not obvious that he sustained a concussion (no LOC or obvious amnesia or balance problems). However, when tested with the SCAT3 approximately 3 hours following the injury, he endorsed a heavy burden of symptoms (score = 16, severity = 42), his cognitive functioning was broadly normal (SAC = 26), he passed the Coordination exam, and his balance was on unusually high classification range (M-BESS = 10) Again, baseline testing is not necessary to appreciate that he was adversely affected by the concussion (individual baseline SAC score was 28 and M-BESS score was 1).

The strength of our study is the large sample size and the pragmatic study design. The normative reference values can be applied to everyday practice by clinicians. The study also has limitations that should be acknowledged. The background information was solely based on self-report and therefore can be partly incorrect.\(^{19}\) Additionally, important background information (e.g., previous lower limb injuries, neurological problems, sleep history) that might have influenced baseline performance were not assessed. The possibility of selection bias in player recruitment exists. Additionally, a small number of the SCAT3 forms had partially missing data for unknown reasons. The effect of inter- and intra-observer variation on the SCAT3 results should be studied in the future. Finally, we focused on a very narrow demographic group of athletes and therefore these results cannot be easily generalized into populations outside professional male ice hockey.\(^{29}\)

5. Conclusions

This study provides representative normative reference values for the SCAT3 for professional male ice hockey players in Finland. There was notable variability on the athletes’ baseline performance on the individual SCAT3 components. In the context of post-injury testing, these normative scores help to distinguish what is abnormal and possibly related to the injury.

6. Practical implications

- There is variability in how athletes endorse baseline symptoms, and how they perform on the cognitive and balance measures. These normative values may help the clinician interpret what is broadly normal and what is unusual following a concussion.
- Neck pain is the most common symptom reported during SCAT3 baseline testing among professional male hockey players.
- Tandem gait and M-BESS appear to assess different aspects of balance and postural stability.

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References

III

Interpreting change on the SCAT3 in professional ice hockey players

by
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2017


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Original research

Interpreting change on the SCAT3 in professional ice hockey players

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ABSTRACT

Objectives: To examine test–retest reliability of the SCAT3 for two consecutive seasons using a large sample of professional male ice hockey players, and to make recommendations for interpreting change on the test.

Design: A cross-sectional descriptive study.

Methods: Preseason baseline testing was administered in the beginning of the seasons 2013–2014 and 2014–2015 to 179 professional male hockey players in rink side settings.

Results: The test–retest reliabilities of the SCAT3 components were uniformly low. However, the majority of athletes remained grossly within their own individual performance range when two pre–season SCAT3 baseline scores were compared to published normative reference values. Being tested by the same person or a different person did not influence the results. It was uncommon for the Symptom score to worsen by ≥ 3 points, the Symptom Severity score to worsen by ≥ 5 points, SAC total score to worsen by ≥ 3 points, M-BESS total error points to increase by ≥ 3, or the time to complete Tandem Gait to increase by ≥ 4 s; each occurred in less than 10% of the sample.

Conclusions: The SCAT3 has low test–retest reliability. Change scores should be interpreted with caution, and more research is needed to determine the clinical usefulness of the SCAT3 for diagnosing concussion and monitoring recovery. Careful examination of the natural distributions of difference scores provides clinicians with useful information on how to interpret change on the test.

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1. Introduction

Head and brain injuries, especially concussions, are common and important health issues in collision sports. Ice hockey is a sport characterized by high velocity, rapid changes in direction, and injuries caused by collision with other players, boards, sticks, or pucks. The systematic collection of injury reports from team medical staff shows that the most commonly injured body region in professional male ice hockey is a player’s head.1,2

The rink side or sideline recognition of sport-related concussion relies on a clinician’s evaluation. Injury mechanics, visible signs, reported symptoms, changes in cognitive and physical performance related to concussion, and exclusion of spinal injury are the key points of assessment. International guidelines for sport-related concussion recommend the use of the Sport Concussion Assessment Tool – Third edition (SCAT3) as a supportive instrument in concussion diagnostics.3–5 Post-injury SCAT3 scores are best interpreted when compared with either an accurate and reliable individual baseline or to age- and sport-specific normative data.6,7

Annual pre-season concussion baseline testing (e.g., computer-based neuropsychological assessment) is common practice in many professional contact sports. However, there are very few published studies on how often baseline testing should be administered. For example, the SCAT3 is a widely used concussion assessment instrument that has no evidence-based guidelines regarding baseline
testing frequencies or intervals. For accurate comparisons between post-injury and baseline performance, it is essential to know how consistent the test–retest results are (i.e., the reliability and stability of the baseline SCAT3 assessment over time). One factor that could influence reliability is learning effect. It is not known if SCAT3 performance is improved by learning when repeatedly done, and if so how long this learning effect lasts.

The purpose of this study was to examine the long-term test–retest reliability of SCAT3 assessments in a realistic clinical setting to better understand normal variation of the scores. We also aimed to describe if there is a significant difference between intra- and interrater reliability and whether the common practice of administering SCAT3 baseline on an annual basis is an ideal time frame or not. Suggestions for interpreting change on the SCAT3 are offered.

2. Methods

This study is a part of a larger research project that strives to translate international recommendations regarding diagnosis and management of concussions into practice in Finnish professional ice hockey. Ethics approval for the study was obtained from the Ethical Committee of Pirkanmaa Hospital District, Tampere, Finland (code: R13070), and each participating subject signed written informed consent according to the Declaration of Helsinki. This study was financially supported by the Finnish Ministry of Education and Culture, the Finnish Hockey League, the Finnish Medical Foundation, and the Maire Taponen Foundation. There was no involvement with any commercial sponsor for this study regarding the study design; the collection, analysis, and interpretation of data; the writing of the report; or the decision to submit the paper for publication.

SCAT3 baseline testing became mandatory for all players in the highest Finnish professional male ice hockey league before the season 2013–2014, but there was not a requirement to do this annually. The total number of athletes playing in the league in two consecutive seasons (2013–2014 and 2014–2015) was 309. Only annually completed preseason SCAT3 baseline tests administered for seasons 2013–2014 and 2014–2015 were included in this study. The number of players who completed both pre-season SCAT3 baseline tests was 179 (58%). Most of the players who were not included in the study completed only one baseline. A small number of athletes were not included for various reasons (e.g., being injured in the time of preseason baseline testing).

In an effort to replicate how the SCAT3 assessment is given clinically, every player was tested individually, at least ten minutes after physical exertion, by the teams’ current medical staff, who were trained to administer SCAT3 in accordance with the SCAT3 instructions in regional training sessions led by the authors before the season 2013–2014. If a player had sustained a concussion prior to testing, he had to have been asymptomatic and participated at least one month in normal game play after the concussion and before the SCAT3 baseline was administered. Demographic variables and medical history were obtained at the time of testing using the Background section of the SCAT3 form. Due to language difficulties with non-Finnish and non-English speakers, this subgroup (n = 8) was excluded from the statistical analysis of the symptom evaluation and the SAC components. The Finnish translation of the SCAT3 was accomplished by a professional translator and reviewed by the authors to maintain the original denotation and connotation of items instead of exact literal or syntactical equivalence.

Descriptive statistics [mean (M), median (Md), standard deviation (SD), interquartile range (IQR)] for both seasons and the individual differences between the test–retest results of the SCAT3 components were calculated. The relationships between five categorical background variables and test–retest differences were examined. Categorical background variables included: (i) examiner; same/different, (ii) age under 20-years: yes/no (iii) self-reported history of concussions during seasons 2012–2013 and 2013–2014: yes/no, (iv) language of testing: native/non-native, (v) history of headache or migraine: yes/no. The data related to learning or attention problems (n = 1) and psychiatric problems (n = 1) could not be meaningfully analyzed due to small sample sizes.

The normality of the data was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The distribution of the scores in every component of the baseline SCAT3 were skewed so the correlations between two continuous variables were measured using the Spearman rho coefficient, Kendall’s tau b, and Wilcoxon Signed-Rank test. Categorical variables in relation to continuous variables (individual test–retest absolute difference scores) were tested with the Mann–Whitney U test (MWU). The level of statistical significance was set at 0.05. IBM SPSS Statistics 21.0 (IBM Corp. Armonk, NY, USA) was used to perform the analyses.

3. Results

The athletes were between the ages of 16 and 38 (M = 25.4, SD = 5.1) years and 19 (10.6%) players were under 20 years before the first SCAT3 baseline test. The Finnish version of SCAT3 was used with 164 (95.5%) Finnish players; the others were tested with the English version. All athletes were Caucasian. The total number of medical staff who served as examiners was 33. More than one-third (35.8%, n = 64) were tested by the same person before both seasons. The average time between athlete’s two baseline tests was 367 days (SD = 24.2, IQR = 360–378). A minority (n = 25, 14%) of the players reported history of headache or migraine. A history of concussion was reported by 56.4% of the players, and 17.9% of all athletes reported having been hospitalized or undergone neuroimaging following a head trauma before the first SCAT3 baseline test. Eleven (6.6%) of them reported sustaining a concussion during the season (2012–2013) preceding the first SCAT3 baseline test in 2013. The number of athletes reporting a concussion between the two baselines was 31 (17.3%; i.e., during the 2013–2014 season or prior to preseason testing in 2014).

The descriptive statistics and test–retest correlations for the SCAT3 components in two consecutive seasons are presented in Table 1. In general, at the group level, most of the SCAT3 mean baseline scores remained stable within the one-year interval. The test–retest correlations, however, were uniformly low, with 8/11 scores having a Spearman coefficient of 0.3 or lower. We have previously published normative reference values for the SCAT3 components. Those normative reference values were based on the pre-season SCAT3 test results of season 2013–2014 (n = 304 athletes), and they are reprinted in Table 2. The percentages of the players who were categorized in the same normative classification range in both preseason baseline tests are presented in Table 3. As seen in column two, most of the players scored in the same normative classification range at both test and retest, and the large majority scored either in the same classification or a higher classification.

The distributions of the individual test–retest absolute difference scores are presented in Figs. 1–6. The absolute difference scores of the SCAT3 components: Symptom score and severity, SAC, M-BESS, and Tandem gait had no statistically significant association with examiner (same/different), age (under/over 20 years), history of headache or migraine (yes/no), or self-reported history of concussion between baselines (yes/no). Better scores on concentration, a subcomponent of the SAC, were obtained by athletes that were tested by the same person in both baselines (positive ranks 45.3%
vs. 29.5%; MWU = 2817.5, p = 0.01). All other subcomponents of SAC and M-BESS did not differ. Only three (1.7%) athletes failed the Coordination test on the first baseline test, and only four (2.2%) players failed the Coordination test during the second baseline. None of these players made errors on this test during both seasons. Over the two season baseline testing, none of the athletes made errors in the double leg stance of the M-BESS.

Fig. 1 illustrates the distribution of test–retest difference scores for all subcomponents of the SCAT3. By examining the values in the grey shaded regions to the left of each figure, it is possible to identify unusual worsening in performance (i.e., difference scores that are found in only 10% or 5% of uninjured athletes). Worsening means greater symptoms, greater error points on the M-BESS, greater time on the Tandem Gait, or lower scores on the SAC. Most athletes (75.6%) do not show test–retest changes of those magnitudes in any subcomponent of the SCAT3. More refined analyses of changes scores, for each SCAT3 component, are provided in Figs. 2–6. As seen in Fig. 2, an increase (worsening) of two or more symptoms at retest occurred in 14.7% of players, and an increase of three or more symptoms occurred in only 10%. As seen in Fig. 3, a total symptom severity score that increases (worsens) by three or more points occurred in 14.1% of athletes, and an increase by five or more points occurred in only 8.8%. As seen in Fig. 4, worsening of two or more points on the SAC occurs in 15.5% of professional athletes, and wors-
Table 3

The percentages of the players who were categorized in the same (same or better) normative classification range as the previous preseason baseline test.

<table>
<thead>
<tr>
<th>Total Sample</th>
<th>Concussion between baselines</th>
<th>Baseline tests performed by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Symptom Score</td>
<td>72.4 (87.1)</td>
<td>70.7 (86.4)</td>
</tr>
<tr>
<td>Symptom Severity</td>
<td>70.6 (85.9)</td>
<td>69.3 (85.0)</td>
</tr>
<tr>
<td>SAC total score</td>
<td>76.8 (88.1)</td>
<td>76.8 (90.6)</td>
</tr>
<tr>
<td>SAC orientation</td>
<td>82.9 (89.4)</td>
<td>82.1 (93.6)</td>
</tr>
<tr>
<td>SAC immediate memory</td>
<td>89.4 (94.7)</td>
<td>90.7 (96.4)</td>
</tr>
<tr>
<td>SAC concentration</td>
<td>92.3 (95.9)</td>
<td>92.1 (96.4)</td>
</tr>
<tr>
<td>SAC delayed recall</td>
<td>74.2 (91.2)</td>
<td>75.9 (84.4)</td>
</tr>
<tr>
<td>M-BESS total errors</td>
<td>75.3 (90.8)</td>
<td>78.3 (93.7)</td>
</tr>
<tr>
<td>M-BESS single leg stance</td>
<td>77.4 (91.0)</td>
<td>79.4 (92.5)</td>
</tr>
<tr>
<td>M-BESS tandem stance</td>
<td>82.3 (92.6)</td>
<td>84.0 (95.1)</td>
</tr>
<tr>
<td>Tandem Gait</td>
<td>72.7 (88.1)</td>
<td>70.3 (81.0)</td>
</tr>
</tbody>
</table>

Note: Normative reference values from Hänninen and colleagues, presented in Table 2, were used. Percentages who were in the same and same or better (in parentheses) classification range on retesting are presented for the total sample, for those who sustained a concussion between the two baselines, and for those tested by the same or a different examiner.

Fig. 1. The distributions of individual test–retest absolute difference scores.

Note: Athletes who had the exact same score (test–retest difference score = 0), better score (fewer symptoms; more errors on the SAC; fewer errors on the M-BESS; faster time in Tandem Gait), and worse score during the second baseline. Worse 10% and 5% in gray. Midmost 90% in dotted line box.

Discussion

This large-scale study of the one-year test–retest reliability of the SCAT3 revealed several important findings for researchers and clinicians. First, the test–retest reliabilities of each component were uniformly low and mostly considered weak according to conventional standards for interpreting stability of human performance tests (see Table 1). The symptom scores had the largest test–retest correlations. These low correlations are related, in part, to the skewed distributions of the test scores. The limited number of options in the scoring of each SCAT3 component results in limited variability and ceiling effects (accumulation of the scores for a large percentage of people, usually to minimum and/or maximum score), which causes bias to reliability estimations and may reduce the magnitude of correlations. When tests, such as the SCAT3, are used for clinical decision making, it is important for the test to have adequate reliability and validity for the intended purpose and with the specific clinical population with which it is being used. The problems with reliability, illustrated in this study, are partially mitigated by having normative reference values (Table 2) and natural distributions of change scores (the Figures) for the SCAT3 components in professional hockey players. Second, the athletes’ level of performance, as a group (as reflected by mean and median scores),
Fig. 2. The distribution of individual test–retest absolute difference scores (Symptom Score). Note: Athletes who had the exact same score (test–retest difference score = 0), better score, and worse score in the second baseline. A worse score indicates an increase in number of symptoms reported.

Fig. 3. The distribution of individual test–retest absolute difference scores (Symptom Severity). Note: Athletes who had the exact same score (test–retest difference score = 0), better score, and worse score in the second baseline. A worse score indicates an increase in severity of symptoms reported.
remained stable from test to retest across the components of the SCAT3. Nearly equal number of athletes showed improvement and declines over the test–retest interval for the Symptom score, Symptom Severity score, and Tandem Gait; in contrast, performance on the SAC and M-BESS was more likely to improve on the second baseline test. Third, there was no statistically significant difference

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**Fig. 4.** The distribution of individual test–retest absolute difference scores (SAC total).

*Note:* Athletes who had the exact same score (test–retest difference score = 0), better score, and worse score in the second baseline.

<table>
<thead>
<tr>
<th>SAC</th>
<th>Worse score (risk pos = 9)</th>
<th>Similar score</th>
<th>Better score (risk pos = 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

---

**Fig. 5.** The distribution of individual test–retest absolute difference errors (M-BESS total).

*Note:* Athletes who had exact as many errors (test–retest difference errors = 0), less errors (better performance), and more errors (worse performance) in the second baseline.

<table>
<thead>
<tr>
<th>M-BESS total errors</th>
<th>Worse performance (risk pos = 9)</th>
<th>Similar</th>
<th>Better performance (risk pos = 49)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17 12 9 7 6 5 4 3 2 1 0 1 2 3 4 5 6 9 10 11 13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---
related to whether the SCAT3 was administered by the same or a different examiner. Fourth, there were no differences in test–retest difference scores in those who sustained a concussion between the two baseline assessments and those who did not. Finally, most players (i.e., 71–92%) obtained scores that were in the same normative classification range at both test and retest, based on the norms published by Hanninen et al. Moreover, retest scores were in the same or better normative classification range in 86–96% of athletes. This means that when an athlete is tested a second time, it is very likely that his score will be similar to or better than it was previously.

The information presented in Figs. 1–6 is very useful for clinicians and researchers who want to better understand the natural distribution of test–retest difference scores on the SCAT3. This information can also be used to determine an unusual amount of change (i.e., worsening or improving) in SCAT3 performance in Finnish professional ice hockey players. Based on the current results, 10% or fewer of the athletes showed the following worsening of SCAT3 retest scores: an increase of three or more points on the Symptoms Score, an increase of five or more points on the Symptom Severity score, a worsening of three or more points on the SAC, an increase of three or more error points on the M-BESS, or an increase of four or more seconds on the Tandem Gait. Clinicians should note that professional hockey players perform perfectly or nearly perfectly on the Coordination test and the double-leg stance of the M-BESS, so errors on those tests should be considered abnormal. Clinicians can use the normative classification ranges in Table 2 in combination with these change scores. For example, as seen in Table 2, an increase of three symptoms or five points on symptom severity will usually result in a worsening in the normative classification, too. For the SAC, a decline by three or more points will always result in a worsening in the normative classification range, unless the person scores nearly perfectly at baseline (i.e., a score of 29 or 30). For the M-BESS, an increase of three error points on retesting will often, but not always, result in a change in the normative classification range. The change scores presented in this paper might prove to be particularly useful for identifying deficits in athletes who perform nearly perfectly on baseline SAC and M-BESS testing, because those athletes could worsen in performance but still have scores that are considered broadly normal.

It is important to note, however, that there are no validated rules or guidelines for interpreting change in performance on the SCAT3 in professional or amateur athletes. This requires clinical judgement. For example, an athlete who reports headache and dizziness following a hard check into the boards, and who scores two points lower on the SAC (base rate = 15.5% in uninjured athletes) and obtains two more error points on the M-BESS (base rate = 16.6% in uninjured athletes) compared to his baseline might, in fact, be experiencing the acute effects of concussion even though his change scores are not in the grey area of Figs. 4 and 5, respectively. The grey areas in the figures demarcate change scores that are statistically uncommon in uninjured athletes. The sensitivities of those change scores to the acute effects of concussion, however, are unknown.

This study design was implemented in practical everyday life of professional ice hockey teams in order to maximize the generalizability and the applicability of the results. For this reason, we did not use independent external examiners. Additionally, we explored individual baseline performance changes and not only group level statistics. The strength of our study was the large sample size and the pragmatic study design.

There are several limitations to this study. The athletes’ medical history was based on the SCAT3 form and therefore some relevant disease/injury history (e.g., lower limb injuries, sleep history) was not included. The information on previous concussions was solely based on self-report and it is known that athletes may underes-
timate their past concussions. The possibility of selection bias in player recruitment exists. Finally, we focused on a very narrow demographic group of professional athletes; additional research should be conducted on other sports, levels, genders, and age cohorts.

5. Conclusions

The SCAT3 is designed to be used on the day-of-injury and in the initial days following injury. It is not designed to measure post-acute or long-term effects of concussion. There are no evidence-based guidelines regarding whether or not baseline preseason testing is necessary, and how often to do baseline testing (e.g., yearly or less frequently). More research is needed to determine the optimal frequency of baseline testing with the SCAT3, such as studies comparing reliability over different time periods and studies comparing post-injury scores to baseline scores after varying time intervals. It is reasonable to assume that the best way to interpret SCAT3 scores is a combination of comparing an athlete’s post-injury scores to a reliable personal baseline and to quality normative data. However, the SCAT3 has low test–retest reliability, making test–retest comparisons challenging. Careful examination of the natural distributions of difference scores provides clinicians and researchers with useful information on how to interpret change on the test. It is important for clinicians and researchers to appreciate that symptom scores can increase as a result of multiple factors separate from concussion, and some variability in test–retest performance is common on the performance-based measures (i.e., SAC, M-BESS, and Tandem Gait) in uninjured athletes.

Practical implications

• It is important to appreciate that SCAT3 symptom reporting can be affected by several factors separate from concussion, and some variability in the balance and cognition measures is common.
• Despite low test–retest reliability of the SCAT3, most players have scores that fall within a similar normative classification range across a one-year test–retest interval.
• Careful examination of the natural distributions of difference scores provides clinicians and researchers with useful information on what should be considered unusual or rare changes in performance in uninjured athletes.

Disclosures

Grant Iverson has been reimbursed by the government, professional scientific bodies, and commercial organizations for discussing or presenting research relating to mild TBI and sport-related concussion at meetings, scientific conferences, and symposiums. He has a clinical and consulting practice in forensic neuropsychology involving individuals who have sustained mild TBIs (including professional athletes). He has received research funding from several test publishing companies, including ImPACT Applications, Inc., CNS Vital Signs, and Psychological Assessment Resources (PAR, Inc.).

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References

IV

Sport Concussion Assessment Tool: Interpreting day-of-injury scores in professional ice hockey players

by

Hänninen T, Parkkari J, Tuominen M, Öhman J, Howell DR, Iverson GL, Luoto TM.

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Abstract

Objectives: To characterize the clinical utility of Sport Concussion Assessment Tool 3 (SCAT3) baseline and normative reference values for the assessment of acute concussion; and to identify the sensitivity of each SCAT3 subcomponent to the acute effects of concussion.

Design: Prospective cohort

Methods: The day-of-concussion SCAT3 results (n=27) of professional male ice hockey players (mean age=27, SD=4) were compared to athlete’s individual baseline and to the league’s normative reference values. Normative cutoffs corresponding to 10th percentile and natural distribution change cutoffs corresponding to 90th percentile cumulative frequency were considered uncommon.

Results: The percentages of the players with uncommon day-of-injury performance, when post-injury scores were compared to individual baseline versus (vs.) normative values, were as follows: Symptoms: 96% vs. 100% (Post-injury Score: M=12, Md=12, SD=4; Severity M=26, Md=23, SD=13); Standardized Assessment of Concussion (SAC): 33% vs. 27% (Post-injury M=25, Md=26, SD=3); modified-BESS (M-BESS): 46% vs. 46% (Post-injury M=7, Md=5, SD=7); Tandem gait: 18% vs. 31% (Post-injury M=11, Md=12, SD=4); Coordination: both 8%. The number and severity of post-injury symptoms were significantly greater, with extremely large effect sizes (Cohen’s d=2.44-3.92), than normative values and individual baseline scores. The post-injury SAC score was significantly lower relative to both baseline (d=0.68) and normative values (d=0.88). The post-injury M-BESS performance was significantly worse when compared to both individual baseline (d=1.06) and league normative values (d=1.46). No significant day-of-injury Tandem Gait deficits were observed using either comparison method.

Conclusions: SCAT3 league normative values were as sensitive as individual baseline scores during day-of-injury assessments. Symptoms were the most sensitive post-concussion component of the SCAT3.

Keywords: brain injuries; concussion; head injuries; baseline testing; ice hockey; sports injury
Introduction

Acute concussion recognition leading to immediate removal from play reduces the likelihood of more severe injuries and prolonged recovery in sports.\textsuperscript{1,2} However, recognition remains challenging due to the lack of an explicit definition of the lowest threshold\textsuperscript{3} of a clinically, radiologically, neurometabolically, or neuropsychologically significant concussion. Deficits in cognitive functioning,\textsuperscript{4} postural stability,\textsuperscript{5} and dynamic balance control\textsuperscript{6} have been reported after concussion, along with diverse physical, cognitive, and emotional symptoms.\textsuperscript{7} Therefore, on an individual level, effects from concussion manifest in diverse clinical presentations.

Concussion is defined as a clinical syndrome arising from a traumatically induced time-limited disturbance of brain functions.\textsuperscript{8} A concussion diagnosis relies on clinician judgment. Multi-modal clinical assessments have been designed to measure the diverse acute effects of concussion. The Sport Concussion Assessment Tool (SCAT; third edition SCAT3)\textsuperscript{9} is used widely by sports medicine clinicians for the acute assessment of athletes with suspected concussion. The standardized approach documents injury mechanism, presence of amnesia, signs of concussion (e.g. disorientation or confusion), and level of consciousness. Several tests compose the SCAT3, including a symptom rating scale, a postural stability test (Modified Balance Erroring System, M-BESS), a timed Tandem gait test, a finger-to-nose coordination test, and a cognitive screen (Standardized Assessment of Concussion, SAC).

No formal SCAT interpretation guide has been published, leaving clinicians to develop their own interpretive approach. Following a suspected concussion, clinicians can compare post-injury SCAT results to individual baseline performance (obtained when uninjured; e.g. pre-season),\textsuperscript{10} to published normative reference values,\textsuperscript{11} or to both.\textsuperscript{10-12} When using individual baseline data as a comparison to post-injury performance, the relatively low test-retest reliability for the SCAT should be considered,\textsuperscript{11} along with the few studies discussing change interpretation on each SCAT component.\textsuperscript{13,14} In contrast, if using normative reference values as a comparison to post-injury
performance, clinicians are limited by the characteristics of athletes (e.g., age, sport, sex) used for dataset development.\textsuperscript{15}

The purpose of the present study was to improve the clinical methodology for interpreting acute post-injury SCAT3 performance. We recently developed SCAT3 normative reference values, using preseason (2013-2014) baseline data from a large sample of Finnish professional hockey league athletes.\textsuperscript{16} We also examined test-retest reliability and developed a method for interpreting change on the SCAT3 in professional hockey players.\textsuperscript{13} We had two aims in the current study: (i) to describe day-of-injury performance on the SCAT3 and (ii) to determine the ability of pre-injury individual SCAT3 baseline scores and normative reference values to detect acute deficits resulting from concussion.
Methods

The Finnish Ice Hockey league uses a concussion protocol that recommends day-of-injury SCAT3 testing for all players with suspected concussion and subsequent follow-up evaluations. Of the reported day-of-injury SCAT3s, between seasons 2013-2016, a total of 29 concussion diagnoses were made for 27 different players. The final diagnosis and return to play (RTP) day were recorded for each athlete by the team physician. Two players had two concussions. Regarding these two players, only their first concussion was included in the statistical analyses of this study. Additionally, four cases who underwent day-of-injury SCAT3 testing were diagnosed with other injuries [cervical sprain (n=2) and facial contusion (n=2)]; they did not sustain a concussion. The SCAT3 scores of these four non-concussed athletes are not included in the statistical analyses. They are presented in Tables S4 and S5 for comparison to the scores of athletes who sustained a concussion.

Athletes diagnosed with a concussion (n=27) were between 19 and 35 (M=27, SD=4) years of age on the day of injury; all were Caucasian. The Finnish translation\textsuperscript{17} of the SCAT3 was used with Finnish players (n=22, 81%), all others were tested in English. The SCAT3 translation was performed by a professional translator and reviewed by the authors to maintain the original denotation and connotation of items instead of exact literal or syntactical equivalence. The day-of-injury SCAT3 was administered by the team medical provider. Team medical staff members were trained by the authors to administer both baseline and post-injury SCAT3s in accordance with the SCAT3 instructions (in sideline settings, 10 or more minutes post-exercise). Barefoot performance in M-BESS and Tandem Gait tests were recorded. Eight teams and 14 examiners were involved in post-injury testing. Of the athletes, 44% (n=12) were tested by the same person during preseason and post-injury testing sessions. Baseline to post-concussion test administration time intervals varied from 1 to 560 days (M=127, Md=79, SD=122). Of the concussed athletes, 88% (23 of 26) reported a prior concussion history; 22% (6 of 27) reported prior hospitalization or neuroimaging following head trauma; 11% (3 of 27) reported a prior history of headache or migraine; and none reported a history of learning, attention, or psychiatric problems. The median time to RTP was 8 days (M=21,
SD=48, range=4-248) with 33% of the players remaining out of play for more than 10 days. Potential signs of concussion (loss of consciousness, balance/motor incoordination, disorientation/confusion, loss of memory, or blank or vacant look) were observed in 10 (37%) cases.

The league normative data and a large test-retest sample of uninjured players were used to calculate the cutoff scores for uncommon SCAT3 performance in this study. The league normative data are based on preseason 2013-2014 baselines of 304 players who were between the ages of 16 and 40 years (M=25.3 years, SD=5.2). The normative data are described in detail in a prior publication. A large test-retest sample of 179 players, baseline tested a second time prior to the 2014-2015 season, were also used in this study. This test-retest sample has been described in detail in a prior publication.

The comparison between the two interpretation methods (i.e., comparison to normative reference values and comparison to baseline scores) was performed by selecting the 10th percentile cutoff as a limit of uncommon performance for each method. We selected the 10th percentile in an attempt to improve sensitivity and maintain specificity at a reasonable level. That is, we were willing to accept a possible 10% false positive rate in order to detect a possible concussion-related deficit on each component of the SCAT3. Accordingly, post-injury values that were identified as uncommon were defined in two ways. First, according to normative values as previously described: Symptom Score=4 or greater, Symptom Severity=6 or greater, SAC=24 or lower, M-BESS=6 or greater, and Tandem Gait=12.9 or greater. Second, uncommon change in performance was defined according to the change from baseline to post-injury as: Symptom Score=+3 or greater, symptom severity=+5 or greater, SAC=−3 or lower, M-BESS errors=+3 or greater, and Tandem Gait=+4 seconds or greater, when post-injury scores were compared to personal baseline scores.

The individual post-injury to baseline change score, hereafter referred to as “baseline-adjusted post-injury score”, was calculated by subtracting the players’ most recent preseason baseline score from the day-of-injury score. The two-season test-retest change score, hereafter referred to as “test-retest difference score”, was calculated by subtracting the season 1 baseline score
from the season 2 baseline score. This was done to illustrate normal test-retest variability in the sample, and to ensure that test-retest variability among the current sample of participants was similar to the variability reported for the league.\textsuperscript{13}

Descriptive post-injury characteristics \([M, \text{Md}, SD, \text{interquartile range (IQR)}]\) for concussed athletes were calculated. Variable distribution normality was assessed with Kolmogorov-Smirnov and Shapiro-Wilk tests. Because of skewed distributions, non-parametric Mann-Whitney U tests were used to examine between-group (Day-of-injury vs. league normative value) differences and Wilcoxon Signed Ranks tests for within-subject (day-of-injury vs. own baseline) differences. Cohen’s d was used to estimate effect sizes. Statistical significance was set at \(p<0.05\). Receiver operating characteristic (ROC) curves were calculated to examine the classification accuracy for injured and non-injured athletes. Each SCAT3 component was analyzed in two ways: (i) comparing post-injury scores (\(n=27\)) to preseason 2013-2014 normative reference value scores of non-injured players (\(n=283\)) and (ii) comparing baseline-adjusted post-injury scores (\(n=27\)) to test-retest difference scores of non-injured players (\(n=159\)) who were baseline tested prior to both 2013-2014 and 2014-2015 seasons. Due to the possible effects of language difficulties with non-Finnish and non-English speakers, this subgroup (\(n=3\)) was excluded from the statistical analyses of the symptom evaluation and the SAC components. IBM SPSS Statistics 21.0 (IBM Corp. Armonk, NY, USA) was used to perform all analyses.

Ethics approval for the study was obtained from the Ethical Committee of Pirkanmaa Hospital District, Tampere, Finland (code: R13070). Each participating athlete signed written informed consent according to the Declaration of Helsinki.
Results

The total number and severity of post-injury symptoms were significantly greater than league normative values and individual baseline scores of concussed athletes, with extremely large effect sizes (Cohen’s d=2.44-3.92). The total SAC score was significantly lower on the day of injury relative to both baseline (d=0.68) and league normative values (d=0.88). The number of M-BESS errors committed was significantly greater on the day of injury compared to both individual baseline (d=1.06) and league normative values (d=1.46). No significant day-of-injury deficits were observed using either comparison method for the Tandem Gait. For detailed statistics see Table 1.

The distribution of day-of-injury SCAT3 scores relative to baseline scores among non-injured players are presented in Figure 1. The area under the ROC curves (AUC) and 95% confidence interval (CI) revealed an excellent classification accuracy to distinguish between concussed and non-injured players for Symptom Score (AUC=0.98, CI=0.96-0.99) and for Symptom Severity (AUC=0.98, CI=0.97-1.00). In contrast, the discriminatory ability was poor for the SAC (AUC=0.64 CI=0.50-0.79), the M-BESS (AUC=0.69, CI=0.56-0.82) and the Tandem Gait (AUC=0.56, CI=0.35-0.78). Similarly, baseline-adjusted post-injury scores revealed excellent ability to discriminate between concussed and non-injured players for the Symptom Score (AUC=0.95, CI=0.88-1.00) and Symptom Severity (AUC=0.95, CI=0.88-1.00), but poor classification for the SAC (AUC=0.71, CI=0.59-0.83), the M-BESS (AUC=0.72, CI=0.60-0.84) and the Tandem Gait (AUC=0.55 CI=0.32-0.78). Only two concussed athletes performed poorly on the post-injury Coordination test.

Extensive comparisons between normative reference values and personal baseline SCAT3 scores are presented in a series of tables included as online supplementary material (Tables S1-S6). The rates of concussed players classified in each of the normative groups are presented in Table S1. The percentages of concussed athletes scoring beyond the clinical cutoffs using the normative reference values were as follows: Symptom Score=100%, Symptom Severity=100%, SAC=27%, M-BESS=46%, and Tandem Gait=31%. The distribution of uncommon baseline-adjusted post-injury scores are presented in Table S2. Using the baseline to post-injury change scores, worsening was
detected for 96% on the Symptom Score, 96% on the Symptom Severity Score, 46% on the M-BESS, 33% on the SAC, and 18% on Tandem Gait (see Table S3). Post-injury impairment identification modestly improved if individual and normative reference values were used simultaneously (See Table S3). Detailed individual day-of-injury SCAT3 results are presented in Table S4. The preseason baseline scores of the injured players are provided in Table S5 for comparison.

Table 2 provides the day-of-injury and baseline rates of each symptom. The most commonly endorsed post-injury symptoms were “Don’t feel right”, Headache, and “Pressure in head”. In addition, these symptoms were the most common to worsen compared to baseline. The rates of worsening on the baseline-adjusted post-injury scores are presented in Table S6.

We observed a few clinically interesting features of the SAC subtests among concussed athletes. It appears that any error during the Orientation subtest might be associated with injury. Most athletes (91%) had a perfect baseline performance and only 5% scored worse when their second season baseline was compared to their first season baseline. However, 26% of athletes score 4 or lower (out of 5 possible points) on the Orientation test following concussion. The Immediate memory subtest does not reliably distinguish between concussed and uninjured athletes. The distribution of the scores, likewise the change between consecutive tests, were almost similar when post-injury and second season baseline scores were compared to previous baseline. In regards to the Concentration subtest, a perfect performance does not mean that an injury has not occurred. Twenty-six percent, of the athletes made no errors on this subtest following their injuries. A change on Delayed recall is not a reliable indicator of concussion, but scoring zero is highly suspicious for injury. Only one fifth of the athletes had test-retest difference score of zero on Delayed recall baselines. Furthermore, thirteen percent of the concussed players scored zero on day-of-injury Delayed recall assessment but none of the athletes scored zero on baselines.

Different findings emerge for the three M-BESS stances. For the double leg stance, any error in this subtest is suspicious for injury. All athletes had a perfect baseline performance across two
seasons, but three athletes scored at least one post-injury error. For the single leg stance subtest, our observations suggest that the range of 0-3 errors is inadequate to reliably identify an injured athlete, but scoring more than three errors is suspicious for injury. All of the concussed athletes had less than four baseline errors, but only 26% had a perfect baseline performance. In contrast, more than one-third obtained at least four errors following injury. For the tandem stance subtest, scoring more than 4 errors is highly suspicious for injury. None of the concussed athletes demonstrated more than four baseline errors on this subtest, and 5 of 26 scored maximum 10/10 errors following their concussions.
Discussion

This study provides clinicians and researchers with information to assist with post-injury SCAT3 test interpretation. League normative SCAT3 reference values had a similar degree of sensitivity to acute concussion effects compared to individual baseline scores among professional male hockey players. Self-reported symptoms were the most sensitive component of the SCAT3 to the acute effects of concussion.

The current findings are consistent with a previous study illustrating that SCAT3 administration does not achieve statistically significant added value when using individual baseline as a comparator for post-injury performance, versus normative data.\textsuperscript{11} However, caution is warranted with reliance on normative data comparisons because interpretation should consider age, sex, and perhaps sport as modifying factors, so the normative data used should closely resemble the athlete being tested. Clinicians should also be aware of the limitations of normative reference ranges. For example, an M-BESS error score of 6 or more represents unusually poor performance,\textsuperscript{16} which occurred in 12/26 (46\%) concussion cases in this study. Using normative data only, one athlete (athlete 7, Table S4) who had a substantial worsening in performance compared to his personal baseline would not have been identified as having a problem when using normative data. Because baseline testing often requires significant time, financial, and personnel investments, normative data offers an alternative with high clinical feasibility when available.\textsuperscript{12}

Our finding of significant differences between baseline and acute post-injury assessments for the Symptoms and M-BESS measurements are in line with the data obtained in college and high school athletes.\textsuperscript{10,11} Symptoms discriminated concussed and non-injured players better than other SCAT3 components when either personal baseline or normative reference values were used in this study. Greater sensitivity of immediate post-concussion symptoms compared to acute neurocognitive impairment or postural control deficits is in accord with a previously published meta-analysis.\textsuperscript{18} Also, our observation that the highest post-injury AUC value was within the symptom inventory supports the notion that symptom inventories are the most sensitive post-concussion SCAT3
Nevertheless, reliance on symptoms alone is not recommended among athletic populations, in part because athletes may underreport concussion symptoms.  

This study supports the recommendation to use post-injury findings on SAC along with the other assessments to reinforce clinical decision making. We found no group level SAC differences when comparing post-injury scores with baseline values of the concussed athletes, and only a small effect when compared to league normative values. The average post-concussion SAC scores in this study were higher than in previous work that reported small but statistically significant score decreases within 24 hours of concussion compared to baseline. Another study reported better SAC scores after concussion than the present study, finding a significant learning effect (improvement in control group) instead of post-concussion decreases.

“Don’t feel right”, “headache”, and “pressure in the head” were the most common day-of-injury symptoms. “Feeling like in a fog”, “dizziness” and “confusion” also were common day-of-injury symptoms (79-83%), and rare (0-4%) during baseline testing. These findings are in line with prior work suggesting that athletes reporting these symptoms should be considered injured, whether baseline values are available or not. The most commonly reported baseline symptoms were “fatigue or low energy” and “neck pain”, and they often changed between two consecutive baselines. Accordingly, presence of these symptoms after suspected concussion should be interpreted with caution and compared to individual baselines when available.

Some observations regarding the clinical use of the SCAT3 emerged from this study. First, symptoms are the most sensitive SCAT3 component to classify concussed athletes from uninjured ones during the day of suspected injury. It is important to appreciate, however, that these same symptoms may occur as a result of other clinical conditions or be influenced by factors such as exercise. We found similar symptom score and severity elevations also occurring among players with facial contusions (Players C and D in Table S4). Further research is required to investigate if concussions that result to prolonged return to play times and athletes with other clinical conditions could be recognized more accurately identifying the typical combinations of post-injury symptoms.
and their severities. That would improve clinicians to target their post-injury acts more precise.

Second, the baseline-adjusted post-injury score might be misleading among athletes who report a high number of baseline symptoms. For example, the only concussed athlete, whose baseline-adjusted post-injury Symptom score and severity was not classified as uncommon in this study (Player 8 in Table S4 and Table S5) was also the only injured player having highly elevated symptom reporting during the baseline assessment. Third, the M-BESS and Tandem gait tests appear to measure different aspects of balance control and therefore should be used in a complementary fashion, given that one or the other may detect post-injury deficits. Poor performance following concussion were common on the M-BESS or the Tandem Gait, but none of the concussed athletes had uncommon scores on both tests.

Previous work suggests that 30-60 concussions occur in The Finnish Hockey League annually.24,25 A limitation of this study is that roughly one-fifth of all concussion cases in the league since 2013 were included. Each team had independent common practice to follow up athletes with suspected concussion, but the day-of-injury SCAT3 was used by only some of the teams. Therefore, selection bias may be present, because only some of the teams completed the day-of-injury SCAT3 for the players suspected to suffer from a concussion and some teams followed a different clinical protocol. Finally, the sample for this study was a homogeneous group of professional ice hockey players. The results of this study should be interpreted and applied with caution in other sports. The utility of normative values compared to individual baselines may significantly differ in other samples. Also, we mainly focused on the sensitivity of post-concussion SCAT3; additional research should examine post-injury testing among other injuries, such as cervical sprains or facial contusions.
Conclusions

Using league normative reference values for the SCAT3 and individual baseline scores resulted in similar levels of sensitivity during day-of-injury concussion assessments among professional ice hockey players. The symptoms appear to be the most sensitive post-concussion SCAT3 component.
Practical Implications

- Self-reported day of injury symptoms are the most sensitive SCAT3 component to classify concussion patients from uninjured ones.
- The M-BESS had modest sensitivity to concussion.
- The ability to discriminate between concussed and non-concussed players when using the day of injury SAC Total score and Tandem Gait was limited.
- See Appendix 1 (Online pdf-file): For Clinicians: Suggestions for Interpreting Day-of-Injury SCAT Results
References


<table>
<thead>
<tr>
<th>SCAT3 Component</th>
<th>Day-of-injury</th>
<th>Baselines of Injured Athletes</th>
<th>League Norms</th>
<th>Day-of-injury Compared to Own Baseline*</th>
<th>Day-of-injury Compared to League Norms **</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p</td>
<td>d</td>
</tr>
<tr>
<td>Symptoms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score</td>
<td>12.17 ± 4.38</td>
<td>2.25 ± 3.29</td>
<td>1.50 ± 2.68</td>
<td>&lt;0.01</td>
<td>2.59</td>
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<td>Severity</td>
<td>25.75 ± 13.20</td>
<td>3.42 ± 5.10</td>
<td>2.26 ± 5.17</td>
<td>&lt;0.01</td>
<td>2.44</td>
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<tr>
<td>SAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>25.36 ± 3.33</td>
<td>27.00 ± 1.38</td>
<td>26.99 ± 1.67</td>
<td>0.02</td>
<td>0.68</td>
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<tr>
<td>Orientation</td>
<td>4.63 ± 0.71</td>
<td>4.91 ± 0.29</td>
<td>4.91 ± 0.34</td>
<td>0.06</td>
<td>0.59</td>
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<td>Immediate memory</td>
<td>14.17 ± 1.24</td>
<td>14.42 ± 0.88</td>
<td>14.60 ± 0.63</td>
<td>0.44</td>
<td>0.24</td>
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<tr>
<td>Concentration</td>
<td>5.57 ± 0.99</td>
<td>3.74 ± 0.81</td>
<td>3.86 ± 0.86</td>
<td>0.35</td>
<td>0.20</td>
</tr>
<tr>
<td>Delayed Recall</td>
<td>3.17 ± 1.72</td>
<td>3.79 ± 1.06</td>
<td>3.67 ± 1.07</td>
<td>0.23</td>
<td>0.41</td>
</tr>
<tr>
<td>M-BESS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6.50 ± 7.44</td>
<td>1.74 ± 1.53</td>
<td>2.04 ± 2.53</td>
<td>&lt;0.01</td>
<td>1.06</td>
</tr>
<tr>
<td>Single Leg Stance</td>
<td>3.35 ± 3.59</td>
<td>1.11 ± 0.93</td>
<td>1.44 ± 1.85</td>
<td>0.01</td>
<td>0.98</td>
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<tr>
<td>Tandem Stance</td>
<td>2.73 ± 3.79</td>
<td>0.63 ± 1.04</td>
<td>0.59 ± 1.45</td>
<td>0.01</td>
<td>0.87</td>
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<tr>
<td>Tandem Gait (TG)</td>
<td>11.20 ± 3.87</td>
<td>10.27 ± 1.92</td>
<td>10.76 ± 1.77</td>
<td>0.53</td>
<td>0.22</td>
</tr>
<tr>
<td>Number of cases</td>
<td>n=23-26, TG n=13</td>
<td>n=22-27, TG n=15</td>
<td>n=279-301, TG n=94</td>
<td>n=21-26, TG n=11</td>
<td>n=13-26 vs. 91-279</td>
</tr>
</tbody>
</table>

Note: Descriptive statistics (mean ± SD) for the day-of-injury, preseason baselines of injured athletes, and league normative SCAT3 scores. The day-of-injury scores were compared to the individual baselines using the Wilcoxon Signed Ranks test (WSR). Day-of-injury scores were compared to league normative values using Mann-Whitney U tests (MWU). Effect sizes are estimated using Cohen’s d. Bolded values indicate a statistically significant difference between groups (p<0.05). *Only concussion cases with both day-of-injury and preseason baseline values recorded were used for WSR and Cohen’s d analyses. **Baseline tests of the concussed players were removed from the league normative database before conducting the MWU and Cohen’s d analyses.
Table 2. Percentages of athletes endorsing specific symptoms on the day of concussion compared to during preseason baseline testing.

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Day-of-Injury Symptom Severity Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 or greater</td>
</tr>
<tr>
<td>“Don’t feel right”</td>
<td>100 (4)</td>
</tr>
<tr>
<td>Headache</td>
<td>96 (4)</td>
</tr>
<tr>
<td>“Pressure in head”</td>
<td>92 (13)</td>
</tr>
<tr>
<td>Dizziness</td>
<td>83 (4)</td>
</tr>
<tr>
<td>Fatigue or low energy</td>
<td>79 (29)</td>
</tr>
<tr>
<td>Feeling like “in the fog”</td>
<td>79 (4)</td>
</tr>
<tr>
<td>Neck Pain</td>
<td>75 (46)</td>
</tr>
<tr>
<td>Confusion</td>
<td>75 (0)</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>67 (8)</td>
</tr>
<tr>
<td>Feeling slowed down</td>
<td>63 (4)</td>
</tr>
<tr>
<td>Blurred vision</td>
<td>58 (4)</td>
</tr>
<tr>
<td>Drowsiness</td>
<td>54 (33)</td>
</tr>
<tr>
<td>Nausea or vomiting</td>
<td>50 (4)</td>
</tr>
<tr>
<td>Difficulty remembering</td>
<td>46 (4)</td>
</tr>
<tr>
<td>Balance problems</td>
<td>46 (4)</td>
</tr>
<tr>
<td>Sensitivity to light</td>
<td>42 (4)</td>
</tr>
<tr>
<td>Sensitivity to noise</td>
<td>33 (4)</td>
</tr>
<tr>
<td>Sadness</td>
<td>25 (4)</td>
</tr>
<tr>
<td>Irritability</td>
<td>17 (17)</td>
</tr>
<tr>
<td>More emotional</td>
<td>21 (0)</td>
</tr>
<tr>
<td>Nervous or anxious</td>
<td>17 (13)</td>
</tr>
<tr>
<td>Trouble falling asleep</td>
<td>4 (17)</td>
</tr>
</tbody>
</table>

Note: The percentages of players who reported each symptom on the day of injury, and the percentages of players who reported each symptom during preseason baseline testing are provided in the parentheses.
Figure 1. The frequency distributions of SCAT3 components on concussed and non-injured players

Note: The black line represents the proportions of post-injury scores (n=27). The gray line represents the proportions of preseason 2013-2014 baseline scores among non-injured players (n=279). The vertical line is the cutoff point for the uncommon values. The cutoffs are based on previously published,16 preseason 2013-2014 baseline tests of uninjured players (n=304) in the league. The uncommon values correspond at the maximum of the worst 10th percentile ranks of the normative values.
Table S1. Classification ranges for the SCAT3 components for the normative sample and the concussed players (n=13-26).

<table>
<thead>
<tr>
<th>Broadly Normal</th>
<th>Below/Above Average</th>
<th>Unusually Low/High</th>
<th>Extremely Low/High</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of the Normative Sample</td>
<td>% of the Concussed Sample</td>
<td>% of the Normative Sample</td>
<td>% of the Concussed Sample</td>
</tr>
<tr>
<td><strong>Symptom Score</strong></td>
<td>0-2</td>
<td>80%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>SymptomSeverity</strong></td>
<td>0-3</td>
<td>83%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>SAC</strong></td>
<td>26-30</td>
<td>84%</td>
<td>59%</td>
</tr>
<tr>
<td><strong>Orientation</strong></td>
<td>5</td>
<td>92%</td>
<td>71%</td>
</tr>
<tr>
<td><strong>Immediate memory</strong></td>
<td>14-15</td>
<td>94%</td>
<td>83%</td>
</tr>
<tr>
<td><strong>Concentration</strong></td>
<td>3-5</td>
<td>96%</td>
<td>91%</td>
</tr>
<tr>
<td><strong>Delayed recall</strong></td>
<td>3-5</td>
<td>88%</td>
<td>70%</td>
</tr>
<tr>
<td><strong>M-BESS</strong></td>
<td>0-3</td>
<td>84%</td>
<td>46%</td>
</tr>
<tr>
<td><strong>Single leg stance</strong></td>
<td>0-2</td>
<td>82%</td>
<td>54%</td>
</tr>
<tr>
<td><strong>Tandem stance</strong></td>
<td>0-1</td>
<td>91%</td>
<td>54%</td>
</tr>
<tr>
<td><strong>Tandem Gait</strong></td>
<td>&lt;12.2</td>
<td>77%</td>
<td>46%</td>
</tr>
</tbody>
</table>

**Note:** The cutoffs for classifications are based on, previously published,\textsuperscript{16} preseason 2013-2014 baseline tests of uninjured players (n=304) in the league. Because the distribution of normative values was not normal, as adequate natural distribution ranks as possible was used for the classification cutoffs. The “broadly normal” corresponds at least the best $75^{th}$ percentile ranks; “below/above average” corresponds at the maximum of the worst $25^{th}$ percentile ranks; “unusually low/high” corresponds at the maximum of the worst $10^{th}$ percentile ranks; and “extremely low/high” at the maximum of the worst $2^{nd}$ percentile ranks of the normative values.

**Sport Concussion Assessment Tool: Interpreting day-of-injury scores in professional ice hockey players**

Hänninen T., Jari Parkkari J., Tuominen M., Ohman J., Howell D.R., Iverson G.I., Luoto T.M.

*Journal of Science and Medicine in Sport* 2017
Table S2. Cutoff scores for uncommon and extremely uncommon performance and the rates of concussed athletes classified in each group

<table>
<thead>
<tr>
<th></th>
<th>Uncommon</th>
<th>Extremely Uncommon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Test-Retest Difference Score</td>
</tr>
<tr>
<td>Symptom Score</td>
<td>24</td>
<td>+3 to 4</td>
</tr>
<tr>
<td>Symptom Severity</td>
<td>24</td>
<td>+5 to 6</td>
</tr>
<tr>
<td>SAC Total</td>
<td>21</td>
<td>-3</td>
</tr>
<tr>
<td>M-BESS Total Errors</td>
<td>26</td>
<td>+3 to 4</td>
</tr>
<tr>
<td>Tandem Gait (seconds)</td>
<td>11</td>
<td>4 or more</td>
</tr>
</tbody>
</table>

Note: An uncommon test-retest difference score occurs in fewer than 10%, and an extremely uncommon test-retest difference score occurs in fewer than 5% among uninjured players. Test-retest difference scores for uninjured players were calculated (season 2 score minus season 1 score), using the normative sample of 179 preseason 2013-2014 and second time prior to the 2014-2015 season baseline tested players. Baseline-adjusted post-injury scores (i.e. comparable test-retest difference score for concussed players) were calculated as follows: day-of-injury score minus preseason baseline score.
Table S3. The percentage (%) of the concussed athletes considered performing uncommonly, when different combinations of SCAT3 components were used for assessment.

<table>
<thead>
<tr>
<th>SCAT3 components and their combinations</th>
<th>Post-Injury Score</th>
<th>Baseline-Adjusted Post-Injury Score</th>
<th>Post-Injury Score or/and Baseline-Adjusted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n Unusual</td>
<td>Extremely Unusual</td>
<td>n Unusual</td>
</tr>
<tr>
<td>Symptom Score</td>
<td>23</td>
<td>100</td>
<td>61</td>
</tr>
<tr>
<td>Symptom Severity</td>
<td>23</td>
<td>100</td>
<td>57</td>
</tr>
<tr>
<td>SAC</td>
<td>22</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>M-BESS</td>
<td>26</td>
<td>46</td>
<td>23</td>
</tr>
<tr>
<td>Tandem Gait</td>
<td>13</td>
<td>31</td>
<td>8</td>
</tr>
<tr>
<td>SAC AND M-BESS</td>
<td>22</td>
<td>64</td>
<td>50</td>
</tr>
<tr>
<td>SAC AND Tandem Gait</td>
<td>11</td>
<td>45</td>
<td>18</td>
</tr>
<tr>
<td>M-BESS AND Tandem Gait</td>
<td>13</td>
<td>77</td>
<td>38</td>
</tr>
<tr>
<td>SAC AND M-BESS, AND Tandem Gait</td>
<td>11</td>
<td>82</td>
<td>55</td>
</tr>
<tr>
<td>Symptoms*</td>
<td>23</td>
<td>100</td>
<td>70</td>
</tr>
<tr>
<td>Symptoms AND SAC</td>
<td>21</td>
<td>100</td>
<td>76</td>
</tr>
<tr>
<td>Symptoms AND M-BESS</td>
<td>22</td>
<td>100</td>
<td>77</td>
</tr>
<tr>
<td>Symptoms AND Tandem Gait</td>
<td>11</td>
<td>100</td>
<td>55</td>
</tr>
<tr>
<td>Symptoms AND SAC AND M-BESS</td>
<td>21</td>
<td>100</td>
<td>81</td>
</tr>
<tr>
<td>Symptoms AND SAC AND Tandem Gait</td>
<td>10</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Symptoms AND M-BESS AND Tandem Gait</td>
<td>11</td>
<td>100</td>
<td>73</td>
</tr>
<tr>
<td>Symptoms AND SAC AND M-BESS AND Tandem Gait</td>
<td>10</td>
<td>100</td>
<td>80</td>
</tr>
</tbody>
</table>

Note: Results are expressed separately for league normative reference values [based on 2013-2014 preseason baselines (n=304)], to individual baselines [based on preseason baselines 2013-2014 and 2014-2015 (n=179)] and both of the aforementioned. The performance was considered unusual if the player scored within the worst 10th percentile and extremely unusual if scored within the worst 2nd percentile of the normative reference values in any of the components mentioned in first column. The performance was ruled unusual if the baseline-adjusted score were worse than cutoffs for 80%, and extremely unusual if worse than the cutoffs for 90% normal variation are in any of the components mentioned in first column. * “Symptoms” means that both Symptom Score and Symptom Severity were used.
Table S4. Individual day of injury SCAT3 performance on each subtest

<table>
<thead>
<tr>
<th>Player</th>
<th>Visible Signs</th>
<th>Symptom Score</th>
<th>Symptom Severity</th>
<th>SAC</th>
<th>M-BESS</th>
<th>Tandem Gait</th>
<th>Coordination</th>
<th>Days to return to play</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Post-injury score</td>
<td>Change from baseline</td>
<td>Post-injury score</td>
<td>Change from baseline</td>
<td>Post-injury errors</td>
<td>Change from baseline</td>
<td>Post-injury time</td>
</tr>
<tr>
<td>Player 1</td>
<td>No</td>
<td>12</td>
<td>9</td>
<td>18</td>
<td>12</td>
<td>30</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Player 2</td>
<td>No</td>
<td>8</td>
<td>6</td>
<td>13</td>
<td>11</td>
<td>30</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Player 3</td>
<td>No</td>
<td>6</td>
<td>5</td>
<td>9</td>
<td>1</td>
<td>29</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>Player 4</td>
<td>No</td>
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<td>-1</td>
<td>16</td>
<td>28</td>
<td>0</td>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>Player 5</td>
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<td>19</td>
<td>17</td>
<td>28</td>
<td>25</td>
<td>28</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>Player 6</td>
<td>No</td>
<td>10</td>
<td>10</td>
<td>29</td>
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<td>26</td>
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<tr>
<td>Player 7</td>
<td>No</td>
<td>17</td>
<td>12</td>
<td>34</td>
<td>28</td>
<td>19</td>
<td>-5</td>
<td>7</td>
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<tr>
<td>Player 8</td>
<td>No</td>
<td>9</td>
<td>-6</td>
<td>11</td>
<td>-10</td>
<td>25</td>
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<td>1</td>
</tr>
<tr>
<td>Player 9</td>
<td>Yes</td>
<td>11</td>
<td>11</td>
<td>15</td>
<td>15</td>
<td>N/A</td>
<td>N/A</td>
<td>2</td>
</tr>
<tr>
<td>Player 10</td>
<td>No</td>
<td>6</td>
<td>-4</td>
<td>14</td>
<td>12</td>
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<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Player 11</td>
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<td>11</td>
<td>10</td>
<td>23</td>
<td>22</td>
<td>28</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Player 12</td>
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<td>6</td>
<td>4</td>
<td>23</td>
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<td>19</td>
<td>-8</td>
<td>2</td>
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<td>Player 13</td>
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<td>18</td>
<td>17</td>
<td>34</td>
<td>33</td>
<td>26</td>
<td>-1</td>
<td>2</td>
</tr>
<tr>
<td>Player 14</td>
<td>No</td>
<td>10</td>
<td>7</td>
<td>16</td>
<td>10</td>
<td>28</td>
<td>-1</td>
<td>10</td>
</tr>
<tr>
<td>Player 15</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>30</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Player 16</td>
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<td>17</td>
<td>11</td>
<td>23</td>
<td>22</td>
<td>26</td>
<td>-3</td>
<td>10</td>
</tr>
<tr>
<td>Player 17</td>
<td>No</td>
<td>18</td>
<td>12</td>
<td>40</td>
<td>29</td>
<td>22</td>
<td>-3</td>
<td>12</td>
</tr>
<tr>
<td>Player 18</td>
<td>No</td>
<td>10</td>
<td>7</td>
<td>17</td>
<td>14</td>
<td>26</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>Player 19</td>
<td>Yes</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
<td>-1</td>
<td>N/A</td>
</tr>
<tr>
<td>Player 20</td>
<td>Yes</td>
<td>12</td>
<td>12</td>
<td>19</td>
<td>19</td>
<td>26</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Player 21</td>
<td>Yes</td>
<td>17</td>
<td>17</td>
<td>52</td>
<td>52</td>
<td>19</td>
<td>-3</td>
<td>20</td>
</tr>
<tr>
<td>Player 22</td>
<td>No</td>
<td>19</td>
<td>13</td>
<td>49</td>
<td>37</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Player 23</td>
<td>No</td>
<td>16</td>
<td>15</td>
<td>42</td>
<td>41</td>
<td>26</td>
<td>-2</td>
<td>10</td>
</tr>
<tr>
<td>Player 24</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>6</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>Player 25</td>
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<td>5</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>25</td>
<td>-3</td>
<td>0</td>
</tr>
<tr>
<td>Player 26</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>Player 27</td>
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<td>14</td>
<td>14</td>
<td>50</td>
<td>50</td>
<td>27</td>
<td>1</td>
<td>30</td>
</tr>
</tbody>
</table>

**Cervical sprain injury**

| Player A | No | 2 | 1 | 4 | 3 | 27 | -1 | N/A | N/A | N/A | N/A | 1 | 0 | 1 |
| Player B | No | 3 | 1 | 5 | 3 | 29 | 0  | 1   | 1   | 12  | 0  | 1 | 0 | 4 |

**Facial contusion**

| Player C | No | 22 | 16 | 39 | 30 | 29 | -1 | 0   | 0   | 12  | 2  | 1 | 0 | 1 |
| Player D | Yes| 9  | 7  | 15 | 12 | 25 | 1  | 7   | 5   | 14  | 4  | 1 | 0 | 10 |

**Cutoff limits**

<table>
<thead>
<tr>
<th></th>
<th>Unusual</th>
<th>4</th>
<th>3</th>
<th>6</th>
<th>5</th>
<th>24</th>
<th>-3</th>
<th>6</th>
<th>3</th>
<th>12.9</th>
<th>4</th>
<th>N/A</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely unusual</td>
<td></td>
<td>11</td>
<td>5</td>
<td>19</td>
<td>7</td>
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<td>5</td>
<td>14</td>
<td>N/A</td>
<td>0</td>
<td>-1</td>
</tr>
</tbody>
</table>

**Note:** Colors indicate if the day-of-injury performance is classified as uncommon (red and pink) or normal (green). The performance was considered as uncommon if the post-injury score was within the worst 10th percentile (pink) or worst 5th percentile (red) of the normative reference values. The worsening of performance was considered as uncommon if the change from baseline was more than the cutoffs for the 10th (pink) and 5th (red) percentiles of normative sample.

**Sport Concussion Assessment Tool: Interpreting day-of-injury scores in professional ice hockey players**

### Table S5. Individual baseline performance and test-retest baseline comparisons for the injured athletes.

<table>
<thead>
<tr>
<th></th>
<th>Symptom Score</th>
<th>Symptom Severity</th>
<th>SAC</th>
<th>M-BESS</th>
<th>Tandem Gait</th>
<th>Coordination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline score</td>
<td>Test-retest change</td>
<td>Baseline score</td>
<td>Test-retest change</td>
<td>Baseline score</td>
<td>Test-retest change</td>
</tr>
<tr>
<td>Player 1</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>Player 2</td>
<td>2</td>
<td>-2</td>
<td>2</td>
<td>-2</td>
<td>29</td>
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<tr>
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<td>1</td>
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<td>1</td>
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<td>Player 4</td>
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<td>2</td>
<td>1</td>
<td>25</td>
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<tr>
<td>Player 5</td>
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<td>2</td>
<td>3</td>
<td>3</td>
<td>28</td>
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<tr>
<td>Player 6</td>
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<td>N/A</td>
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<td>Player 7</td>
<td>5</td>
<td>-5</td>
<td>6</td>
<td>6</td>
<td>24</td>
<td>-3</td>
</tr>
<tr>
<td>Player 8</td>
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<td>-5</td>
<td>21</td>
<td>-8</td>
<td>25</td>
<td>1</td>
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<tr>
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<td>1</td>
<td>0</td>
<td>2</td>
<td>27</td>
<td>-1</td>
</tr>
<tr>
<td>Player 10</td>
<td>1</td>
<td>-1</td>
<td>2</td>
<td>0</td>
<td>29</td>
<td>4</td>
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<td>Player 11</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>Player 12</td>
<td>2</td>
<td>-2</td>
<td>2</td>
<td>-2</td>
<td>27</td>
<td>2</td>
</tr>
<tr>
<td>Player 13</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>27</td>
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<tr>
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<td>3</td>
<td>6</td>
<td>6</td>
<td>29</td>
<td>2</td>
</tr>
<tr>
<td>Player 15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>29</td>
<td>1</td>
</tr>
<tr>
<td>Player 16</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>27</td>
<td>-3</td>
</tr>
<tr>
<td>Player 17</td>
<td>6</td>
<td>0</td>
<td>12</td>
<td>5</td>
<td>25</td>
<td>-2</td>
</tr>
<tr>
<td>Player 18</td>
<td>3</td>
<td>N/A</td>
<td>3</td>
<td>N/A</td>
<td>27</td>
<td>N/A</td>
</tr>
<tr>
<td>Player 19</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Player 20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>Player 21</td>
<td>0</td>
<td>N/A</td>
<td>0</td>
<td>N/A</td>
<td>27</td>
<td>N/A</td>
</tr>
<tr>
<td>Player 22</td>
<td>6</td>
<td>-2</td>
<td>12</td>
<td>3</td>
<td>26</td>
<td>-2</td>
</tr>
<tr>
<td>Player 23</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>Player 24</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Player 25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>28</td>
<td>-3</td>
</tr>
<tr>
<td>Player 26</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Player 27</td>
<td>0</td>
<td>N/A</td>
<td>0</td>
<td>N/A</td>
<td>26</td>
<td>N/A</td>
</tr>
<tr>
<td>Player A (cervical injury)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>Player B (cervical injury)</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>29</td>
<td>-1</td>
</tr>
<tr>
<td>Player C (facial contusion)</td>
<td>6</td>
<td>-10</td>
<td>9</td>
<td>-13</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Player D (facial contusion)</td>
<td>2</td>
<td>-1</td>
<td>3</td>
<td>0</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td><strong>Cutoff limits</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unusual (&lt;10%)</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>24</td>
<td>-3</td>
</tr>
<tr>
<td>Extremely unusual (&lt;5%)</td>
<td>11</td>
<td>5</td>
<td>19</td>
<td>7</td>
<td>23</td>
<td>-4</td>
</tr>
</tbody>
</table>

**Note:** Colors indicate if the performance is classified as uncommon (red and pink) or normal (green). The performance was considered as uncommon if the baseline score was within the worst 10th percentile (pink) or worst 2nd percentile (red) of the normative reference values. The worsening of performance was considered as uncommon if the change between test and retest was more than the cutoffs for the 10th (pink) and 5th (red) percentiles of normative sample.

---

**Sport Concussion Assessment Tool: Interpreting day-of-injury scores in professional ice hockey players**

Table S6. The rates of worsening on the baseline-adjusted day-of-injury symptom severity score.

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Baseline-Adjusted Day-of-Injury Symptom Severity Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Worsening of the symptom by 1 or more point</td>
</tr>
<tr>
<td>Headache</td>
<td>96 (5)</td>
</tr>
<tr>
<td>“Don’t feel right”</td>
<td>96 (0)</td>
</tr>
<tr>
<td>“Pressure in head”</td>
<td>92 (5)</td>
</tr>
<tr>
<td>Dizziness</td>
<td>79 (0)</td>
</tr>
<tr>
<td>Confusion</td>
<td>75 (0)</td>
</tr>
<tr>
<td>Feeling like “in the fog”</td>
<td>75 (0)</td>
</tr>
<tr>
<td>Fatigue or low energy</td>
<td>63 (21)</td>
</tr>
<tr>
<td>Neck Pain</td>
<td>63 (20)</td>
</tr>
<tr>
<td>Feeling slowed down</td>
<td>63 (0)</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>63 (5)</td>
</tr>
<tr>
<td>Blurred vision</td>
<td>54 (0)</td>
</tr>
<tr>
<td>Nausea or vomiting</td>
<td>50 (0)</td>
</tr>
<tr>
<td>Difficulty remembering</td>
<td>46 (0)</td>
</tr>
<tr>
<td>Balance problems</td>
<td>46 (0)</td>
</tr>
<tr>
<td>Sensitivity to light</td>
<td>42 (5)</td>
</tr>
<tr>
<td>Drowsiness</td>
<td>33 (21)</td>
</tr>
<tr>
<td>Sensitivity to noise</td>
<td>33 (5)</td>
</tr>
<tr>
<td>Sadness</td>
<td>25 (0)</td>
</tr>
<tr>
<td>More emotional</td>
<td>21 (5)</td>
</tr>
<tr>
<td>Irritability</td>
<td>13 (11)</td>
</tr>
<tr>
<td>Nervous or anxious</td>
<td>13 (5)</td>
</tr>
<tr>
<td>Trouble falling asleep</td>
<td>0 (16)</td>
</tr>
</tbody>
</table>

Note: The percentages of players (n=24) who reported greater symptom severity on the day of injury compared to preseason baseline testing; and the percentages of players who reported greater symptom severity during retesting (from two consecutive seasons, n=19-20) are presented in parentheses.
For Clinicians: Suggestions for Interpreting Day-of-Injury SCAT Results

SCAT has been developed to assist clinicians with recognizing the acute effects of concussion and to improve their ability to distinguish between concussed and non-injured athletes. Although a useful tool, abnormal SCAT performance does not necessarily indicate that an athlete has sustained a concussion, because other factors may influence SCAT scores. Furthermore, some concussed athletes can perform normally on the SCAT.

When using individual baseline data as a comparator to post-injury performance, clinicians should know that some people have test-retest variation in performance in the absence of injury. When using normative reference values as a comparator to post-injury performance, the characteristics of the athlete (e.g., age, sport, sex) should be as similar as possible to the athletes used for the normative reference value development. The comments below are based mostly on the results of the present study, not the entire literature on the SCAT.

**Symptoms**

Symptoms (Score and Severity) are the most common component to worsen on a day-of-concussion SCAT. Day-of-concussion symptoms are usually significantly higher than symptoms reported by non-injured athletes. However, if an athlete reported a high number and/or severity of symptoms during the individual baseline, the health care provider should be cautious when using that score to compare to symptoms reported following a suspected injury. It is best to administer other objective measures in addition to self-reported symptoms to mitigate the potential for underreporting of post-injury symptoms.

Post-injury performance to consider unusual or extremely unusual in professional hockey players:

<table>
<thead>
<tr>
<th>Total number of symptoms endorsed</th>
<th>unusual=4-10, extremely unusual=11+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of symptoms increase compared to baseline:</td>
<td>unusual=3-4, extremely unusual 5+</td>
</tr>
<tr>
<td>Symptom Severity:</td>
<td>unusual=6-18, extremely unusual 19+</td>
</tr>
<tr>
<td>Symptom Severity increase compared to baseline:</td>
<td>unusual=5-6, extremely unusual=7+</td>
</tr>
</tbody>
</table>

- Most common day-of-concussion symptoms:
  - “don’t feel right”, “headache”, and “pressure in the head”

- Other common day-of-concussion symptoms, and rare for uninjured athletes:
  - “Feeling like in a fog”, “dizziness”, and “confusion”

- Most common preseason baseline symptoms:
  - “fatigue or low energy” and “neck pain”

*Journal of Science and Medicine in Sport 2017: Sport Concussion Assessment Tool: Interpreting day-of-injury scores in professional ice hockey players*  
Hänninen T., Jari Parkkari J., Tuominen M., Öhman J., Howell D.R., Iverson G.I., Luoto T.M.
Standardized Assessment of Concussion (SAC)

The ability to discriminate between concussed and non-concussed players when using the SAC is very limited, thus the post-injury findings on SAC should be used along with the other assessments to reinforce clinical decision making. Comparing post-injury performance to individual baseline is recommended.

Post-injury performance to consider unusual or extremely unusual in professional hockey players

<table>
<thead>
<tr>
<th>SAC Total:</th>
<th>unusual=24, extremely unusual=less than 23</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAC Total decrease compared to baseline:</td>
<td>unusual=3, extremely unusual=greater than 3</td>
</tr>
</tbody>
</table>

Interpreting the subcomponents:

- Less than full (5 points) and decrease in the post-injury score compared to baseline score on Orientation are typically abnormal findings
- Immediate memory does not reliably distinguish concussed and uninjured athletes
- Worsening on the Concentration subtest, compared to baseline, is uncommon finding. However, one out of every four of the concussed athletes still scored the full 5 points on the day-of-injury test.
- Some degree of variation on Delayed Recall scores is common in uninjured athletes. A post-injury score of zero should be considered abnormal.

Modified Balance Error Scoring System (M-BESS):

Post-injury performance to consider unusual or extremely unusual in professional hockey players

<table>
<thead>
<tr>
<th>M-BESS Total errors:</th>
<th>unusual=6-10, extremely unusual: 11-30</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-BESS Total errors increase compared to baseline:</td>
<td>unusual=3-4, extremely unusual: 5-30</td>
</tr>
</tbody>
</table>

Abnormal performance on the subcomponents:

- Any error on M-BESS double-leg stance
- 4 of greater errors on single-leg stance
- Maximum (10) errors on tandem-leg stance

Tandem Gait

Post-injury performance to consider unusual or extremely unusual in professional hockey players

<table>
<thead>
<tr>
<th>Tandem gait (seconds):</th>
<th>unusual=12.9-13.9, extremely unusual: greater than 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tandem gait time increase compared to baseline (sec):</td>
<td>unusual= greater than 4</td>
</tr>
</tbody>
</table>

Coordination

Post-injury score of 0 on the Finger-to-nose test should be considered abnormal.