

The Extent to which the King-Devick Test and Sport Concussion Assessment Tool 3  
Predict 3-Dimensional Multiple Object Tracking Speed

by

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BSc, University of Victoria, 2001  
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A Master's Thesis Submitted in Partial Fulfillment  
of the Requirements for the Degree of

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in the School of Exercise Science, Physical and Health Education

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University of Victoria

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## **Supervisory Committee**

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### Abstract

**Objective:** To determine the extent to which aspects of the Sport Concussion Assessment Tool 3 (SCAT3) or Child SCAT3 (C-SCAT3), and the King-Devick Test (KDT) predict Three-Dimensional Multiple Object Tracking (3D-MOT) speed.

**Participants:** A sample of 304 healthy, non-concussed participants with a sporting history (101 females, 203 males) ranging in age from 7-29 years (mean age = 16.05 +/- 4.36) were included in the analysis.

**Methods:** Participants completed the SCAT3, KDT and 3D-MOT in a single visit. **Data Analysis:** A regression analysis was performed to determine the extent to which aspects of the SCAT3 (immediate memory (IM), coordination (COOR), delayed recall (DR)), and the KDT predicted 3D-MOT speed.

**Results:** Using the stepwise method, it was found that KDT, DR and COOR explain a significant amount of the variance in the speed of the 3D-MOT ( $F(3, 256) = 11.82, p < .000$  with an  $R^2 = .12$ ). The analysis shows that KDT (Beta = -0.01,  $p < .000$ ), DR (Beta = 0.07,  $p < .02$ ), and COOR (Beta = .23,  $p < .03$ ), were significant predictors of 3D-MOT speed.

**Conclusions:** This study suggests that the KDT, DR, and COOR significantly account for 12% of the 3D-MOT scores, however, there is a large portion of variability unaccounted for by the SCAT3 or C-SCAT3 and KDT. This shows that 3D-MOT likely accounts for central cognitive functions above and beyond the SCAT3 or C-SCAT3 and KDT. Future studies should examine this relationship at baseline, post-injury, and through concussion recovery. This could provide valuable information to better inform clinicians responsible for making return to play determinations. **Keywords:** Concussion, Mild Traumatic Brain Injury, 3D-MOT, King-Devick Test, Sport Concussion Assessment Tool 3, Child Sport Concussion Assessment Tool 3.

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## List of Abbreviations

KDT - King-Devick Test

SCAT3 - Sport Concussion Assessment Tool 3

C-SCAT3 - Child Sport Concussion Assessment Tool

GCS - Glasgow Coma Scale

IM - Immediate Memory

DR - Delayed Recall

COOR - Coordination

3D - Three Dimensional

MOT - Multiple Object Tracking

CISG - Concussion in Sport Group

CHINCNS - Committee of Head Injury Nomenclature of the Congress of Neurologic Surgeons

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## **Dedication**

To My Amazing Family, I would not have been able to complete this journey without your never-ending flexibility, love, and support!! I am forever grateful for your patience and understanding! XOXOX

## Chapter 1: Introduction and Literature Review

### Introduction

Concussions, also known as mild traumatic brain injury (mTBI), are a significant concern in modern society and have recently achieved a high profile in the news media in the wake of movies such as “Head Games” (James & Sheridan, 2012), and “Concussion” (Landesman et al., 2015). It is estimated that 5-9% of sports injuries in the United States are concussions (Langlois, Rutland-Brown, & Wald, 2006), with an estimated incidence of over 4 million per year (McCrory et al., 2013). Despite the upswing in media attention and public awareness, a significant number of concussions go unreported (Hunt & Asplund, 2010) which poses a significant public health concern. The majority of concussions (80 to 90%) characteristically resolve spontaneously within 7-10 days in adults, but symptoms can be prolonged even longer in children and adolescents (Kuczynski, Crawford, Bodell, Dewey, & Barlow, 2013; McCrory et al., 2005, 2013). Evaluation and monitoring of post-concussion recovery relies heavily on the subjective nature of self-reported symptoms (Balasundaram, Sullivan, Schneiders, & Athens, 2013), however, the presence of concussion-like symptoms have also been reported in non-concussed individuals at rest (Iverson & Lange, 2003; Zakzanis & Yeung, 2011), and after activity (Alla, Sullivan, & McCrory, 2012; Gaetz & Iverson, 2009). Normal post-exertional symptom production leaves athletes vulnerable to false positives when diagnosing concussions (Balasundaram et al., 2013). In addition to the threat of false positive testing, the actual physiological recovery from a concussion was unknown because it was based on the assumption that recovery was complete once subjective self-reported post-concussion symptoms had resolved. Recently, however, it

was identified that complex perceptual deficits have shown to persist beyond the resolution of post-concussion symptoms for up to three months after mTBI (Brosseau-Lachaine, Gagnon, Forget, & Faubert, 2008). Therefore, research is necessary to find objective measures to differentiate between post-concussion impairments and concussion-like symptoms that are not the result of a concussion, as well as identify impairments beyond the resolution of self-reported symptoms to decrease the chances of false positives and premature return to play. To that end, the Government of Canada has recently invested 1.4 million dollars in research with the goal of developing and implementing a standardized evidence-based approach to preventing, managing and increasing concussion awareness within Canada (Government of Canada, 2016b).

Concussions are complex injuries which are difficult to diagnose as there are few objective, scientifically validated, and quantitative measures that can be applied during an assessment. Further, sideline evaluation for concussion can be difficult because of the variability, subjectivity, and elusiveness of symptoms (Putukian et al., 2013). The 4<sup>th</sup> Annual Consensus Statement for Concussion in Sport describes a concussion as a disturbance in brain function, rather than structure, caused by a direct or indirect force to the head which typically manifests as a rapid onset of neurologic dysfunction and symptoms. Further, it is a complex pathophysiological process affecting the brain, induced by biomechanical forces (McCrory et al., 2013). The gold standard for concussion evaluation is the Sport Concussion Assessment Tool 3 (SCAT3) which includes a subjective self-symptom report, a brief neuropsychological test battery that assesses attention and memory function, along with balance and coordination (McCrory et al., 2013). In addition, visual problems are experienced by nearly 30% of athletes

during the first week post-injury (Kontos et al., 2012). Some of the visual impairments experienced post-concussion include deficits in visual attention, accommodation, convergence, saccades, pursuits, higher order and reading deficits (Barnett & Singman, 2015; Kontos, Sufrinko, Elbin, Puskar, & Collins, 2016). With these visual disorders having been identified in both adult and adolescent populations (Master et al., 2016), this presents as a significant limitation of the current gold standard test for concussion identification due to the lack of visual testing within the SCAT3 and C-SCAT3.

Contrastingly, the King-Devick Test (KDT) has been used to assess visual deficits after a concussive event. The KDT tests for symptoms that correlate with suboptimal brain function such as impairment of eye movement, attention, and language (Heitger et al., 2009). Several studies have examined the KDT as a potential concussion screening tool in sports such as football, hockey, soccer, boxing, and rugby (Galetta, Barrett, et al., 2011; Galetta, Brandes, et al., 2011; King, Gissane, Hume, & Flaws, 2015; King, Hume, Gissane, & Clark, 2015). In those studies, the KDT was shown to accurately identify impairments with a high degree of sensitivity and specificity. Thus, the addition of the KDT to current gold standard testing, such as the SCAT3 and C-SCAT3, can improve the ability to detect concussed athletes. While the KDT appears successful at testing for the impairments noted above, it does not assess other ocular motor functions such as pursuit, convergence, and accommodation, all of which have been implicated in mTBI as important indicators of dysfunction (Capó-Aponte, Urosevich, Temme, Tarbett, & Sanghera, 2012; Ciuffreda et al., 2007). This lack of a comprehensive visual assessment tool leads researchers to consider other possible tools, with the potential to measure visual deficits above and beyond those currently assessed by the KDT. Three-

Dimensional Multiple Object Tracking (3D-MOT), is a quantitative objective measure which requires the participant to maintain multi-focal attention on several moving targets at the same time. Evidence suggests that 3D-MOT speed thresholds are an indicator of high-level brain function (Legault & Faubert, 2012; Vartanian, Coady, & Blackler, 2016). The 3D-MOT elicits high-level mental resources, such as complex motion integration and working memory, which are known to be affected by concussion (Brosseau-Lachaine et al., 2008; Faubert & Sidebottom, 2012). The 3D-MOT has been used for performance enhancement, reducing the risk of injury, and has been hypothesized to provide a baseline reference for return to play post-concussion (Kolb, Beauchamp, & Faubert, 2011). The a3D-MOT is quantitative objective measure eliciting high-level mental resources, such as complex motion integration and working memory, which are known to be affected by concussion (Brosseau-Lachaine et al., 2008; Faubert & Sidebottom, 2012) and as such can test components of vision beyond the capabilities of the KDT and SCAT3. Though researchers continue to strive for enhanced approaches to diagnosing and document concussions, there are opportunities for improvement in objective quantifiable measurements of cognitive deficits caused by concussive events. The current study sought to determine the extent to which aspects of the SCAT3 or C-SCAT3, and the KDT predict 3D-MOT speed.

This next section will provide an in-depth review of previous literature which established the foundation for the current research project focusing on defining a concussion, identifying the incidence of concussion and the concern for public health, reviewing the evolution concussion assessment tools, and finally, exploring two newer

concussion assessment tools in addition to the gold standard tool for concussion assessment.

## **Literature Review**

### **What is a concussion?**

Though the notion of an altered mental state dates back over a thousand years (Williams & Danan, 2016), the definition of concussion continues to evolve. The current definition of a concussion describes this phenomenon as a disturbance in brain function, rather than physical structure, caused by a direct or indirect force to the head which typically manifests as a rapid onset of neurologic dysfunction and symptoms. The 4<sup>th</sup> Annual Consensus Statement for Concussion in Sport (2013), further defines concussion as a complex pathophysiological process affecting the brain, induced by biomechanical forces (McCrory et al., 2013). The majority of concussions (80 to 90%) characteristically resolve spontaneously within 7-10 days but symptoms can be prolonged for an average of 21 days in children and adolescents (Kuczynski et al., 2013; McCrory et al., 2005, 2013). The impact forces may result in elongation of white matter axons and produce axonal injury leading to concussion symptoms (Atkins, Newman, & Biousse, 2008; Pinto, Meoded, Poretti, Tekes, & Huisman, 2012). In addition, animal studies indicate concussions can produce a neurometabolic cascade that results in blood flow changes, ionic shifts, mitochondrial changes, and neuronal excitotoxicity (Giza & Hovda, 2001; Pinto et al., 2012). The combination of axonal injury and neurometabolic dysfunction create the signs and symptoms common in concussion. In humans, the onset of signs and symptoms are usually rapid; however, they can also be delayed, becoming evident in a time period that can span a number of days post-

injury (McCrory et al., 2013; Raftery, Kemp, Patricios, Makdissi, & Decq, 2016). Given the elusiveness and variability of symptom presentation, evaluation of a concussion is often challenging both on the sidelines of a sporting event and in the clinical environment. A non-exhaustive list of common concussion signs and symptoms include: headache, pressure in the head, neck pain, nausea or vomiting, dizziness, blurred vision, unstable walking/balance problems, sensitivity to light/noise, feeling slowed down/in a fog, difficulty concentrating/remembering, fatigue or low energy, changes in sleep patterns/drowsiness, emotional changes (irritability, sadness), loss of consciousness, amnesia (anterograde and/or retrograde), general confusion/disorientation, and/or behavior or personality changes (Guskiewicz, Weaver, Padua, & Garrett, 2000; McCrory et al., 2013). Concussions may present with any combination of these symptoms, as symptoms are an individualized phenomenon which can vary from person to person and from concussion to concussion. Further confounding definition and diagnosis, these typical signs and symptoms are not specific to concussions and may appear in individuals for a host of other reasons. Loss of consciousness as a result of a concussion is rare, occurring in less than 10% of all concussion injuries (Guskiewicz et al., 2000; Laker, 2015; McCrory et al., 2013). The symptoms most reported post-concussion are headaches (85%), dizziness and balance problems (77%) (Guskiewicz, 2003). The severity and the number of symptoms have great variability between individuals and are influenced by many factors. This variability led early researchers to establish grading systems that they felt captured all ranges of a concussion. There have been twenty-five different grading systems introduced to aid in the diagnosis and management of concussions to date (Johnston, McCrory, Mohtadi, &

Meeuwisse, 2001; Mccaffrey, Mihalik, Crowell, Shields, & Guskiewicz, 2007), but all were later abandoned due to lack of empirical support (Aubry et al., 2002). As previously defined, a concussion is currently considered an alteration in brain function rather than brain structure as the injury occurs at the cellular and subcellular levels and therefore does not appear on conventional imaging (McCrory et al., 2013). Newer approaches in imaging such as Functional Magnetic Resonance Imaging, Diffusion Tensor Imaging, and Magnetic Resonance Spectroscopy have all shown promise (McCrory et al., 2013), however the sideline evaluation is still based on recognition of injury, assessment of symptoms, cognitive and cranial nerve function and balance (Putukian et al., 2013). Clinical management and return to play decisions remain a judgment from a qualified medical professional on an individualized basis (McCrory et al., 2013).

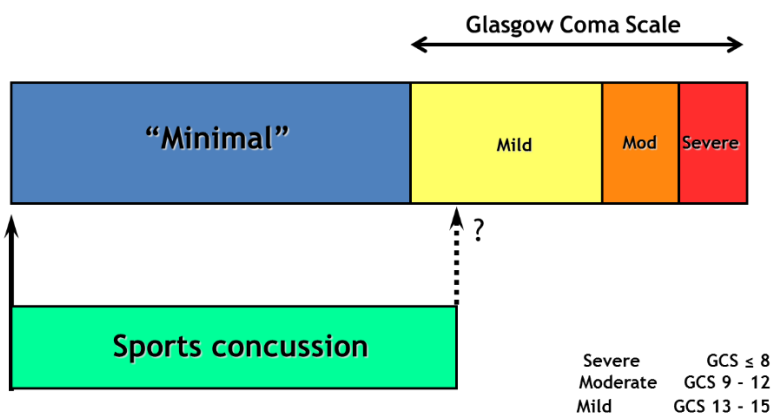
Some researchers have argued that concussions are best considered to be a subset of traumatic brain injury (TBI) (McCrory et al., 2013), however, there continues to be opposition to the use of this terminology as those outside of sport use the terminology to describe different injury constructs of traumatic brain injury (McCrory, 2001; McCrory et al., 2013). The Glasgow Coma Scale (GCS), was initially proposed to distinguish mild, moderate, and severe brain injury six hours post trauma (Jennett & Bond, 1975). The GCS evaluates impaired levels of consciousness through the summation of scores based on 1) eye-opening, 2) motor response, and 3) verbal response. GCS evaluation is shown in Figure 1.

**1 Glasgow coma scale (GCS)**

<b>Best eye response (E)</b>	
No eye opening	1
Eye opening in response to pain	2
Eye opening to speech	3
Eyes opening spontaneously	4
<b>Best verbal response (V)</b>	
No verbal response	1
Incomprehensible sounds	2
Inappropriate words	3
Confused	4
Oriented	5
<b>Best motor response (M)</b>	
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
<b>Glasgow Coma score (E + V + M)</b>	<b>of 15</b>

GCS should be recorded for all athletes in case of subsequent deterioration.

**Figure 1. A depiction of the Glasgow Coma Scale from the Sport Concussion Assessment Tool 3.**



Teasdale et al Lancet 1974; ii: 81-4

**Figure 2. A depiction of the Glasgow Coma Scale proposed to visually explain the traumatic brain injury spectrum. A clinical scale has evolved for assessing the depth and duration of impaired consciousness and coma. A mild head injury has been defined with a score of 13 to 15, moderate head injury with a score of 9 to 12, and severe head injury with a score of 8 or less (Ruijs, Keyser, & Gabreëls, 1994; Teadsale & Jennett, 1974).**

As you can see in Figure 2, although there may be an overlap between sports concussion and the mild brain injury scale, most concussions fall outside the GCS in the minimal category (Teadsale & Jennett, 1974). Researchers, therefore, consider the GCS an inappropriate measure for the determination of all variations of concussion (McCrory, 2001), however, it remains within the assessment protocol to rule out brain injuries that fall within the GCS. Though the 4<sup>th</sup> Annual Consensus Statement for Concussion in Sport has identified concussion as a subset of mTBI (McCrory et al., 2013), further discussion and additional study is required in this area. With this notable difference in opinions surrounding the terminology, many American publications have used the terminology interchangeably. To that end, concussion and mTBI will be used synonymously in this study.

### **Incidence rates for concussions in Canada and the United States of America.**

There appears to be an increase in the frequency of sport-related concussion, which has had a corresponding increase in concern within the sporting and healthcare communities, and those who are responsible for the development of public policy (Government of Canada, 2016). Guskiewicz and colleagues (2000), attributed the apparent increase in the frequency of concussion to the sensationalized and high-profile cases reported in the news media. Whether positive or negative, this has had the definitive effect of increased public awareness which has in turn initiated scientific research to establish and implement concussion education tools within the sporting community. Further, as a result of this increase in awareness, there has been an increase in the presence medical professionals on the sporting sidelines. These professionals are better educated and equipped with current and more effective

identification tools allowing for improved recognition of a concussive event which leads to the immediate removal of athletes from play post-concussive event and immediate sideline assessment. Despite this increase in attention, the true incidence of concussion remains unknown as most estimates are derived from emergency room visits rather than clinical or sideline presentations. Therefore, the assumption is that the data represents only the most severe concussion-related injuries (Morrish & Carey, 2013). The incidence of concussion reported in the hospital emergency departments in the lower mainland of British Columbia, Canada, in 2011 was 16,888, of which 18.3% were sports-related (BC Injury Research and Prevention Unit, 2016). This is consistent with previous literature from the Centers for Disease Control and Prevention which had reported that of the 1.7 million concussions reported per year, 20% were also sports-related (Faul, Xu, Wald, & Coronado, 2010; National Center for Injury Prevention and Control, 2003).

There is also a concern that a concussion can alter a child's developmental trajectory (BC Injury Research and Prevention Unit, 2016), however, the long-term effects of concussions have yet to be adequately elucidated. It is widely accepted that the majority of adults who sustain a concussion will recover naturally without intervention within 7-10 days (McCrory et al., 2013), however, a small percentage of the population may suffer from long-term impairments causing difficulty returning to routine or daily activities (such as work or school) for many weeks or months. In contrast, evidence suggests that children and youth are at greater risk of concussion (BC Injury Research and Prevention Unit, 2016) because they are in a constant state of development and respond differently after a concussion. The most prominent age-

based difference is second impact syndrome. Second impact syndrome, a potentially catastrophic physiological response which can cause death, may occur when a second concussion is sustained before the previous concussion has fully resolved (McCrory et al., 2013). Second impact syndrome is an extremely rare phenomenon (Iverson, Gaetz, Lovell, & Collins, 2004; McCrory et al., 2013), and mostly occurs among youth (age 13 - 18 years). This indicates a vulnerability for this age group (Iverson et al., 2004). In addition, males tend to account for more concussion-related hospitalizations than females, with males being at higher risk in the adolescent and older adult age groups (Morrish & Carey, 2013). Fall-related concussion hospitalizations were highest among 0-4 years old, whereas sport-related concussion rates among 10-19 years old were higher than for the 0-9 years old. In addition to the medical and individual ramifications, concussions are a costly injury with \$2.4 million dollars spent on concussion-related hospitalizations alone in British Columbia, Canada, in 2016 (BC Injury Research and Prevention Unit, 2016).

Although the prevalence of concussion has been documented, there are an astounding number of concussions that go unreported (Hunt & Asplund, 2010), which poses a significant public health concern (Rizzo et al., 2016). An athlete's decision to report an injury can be motivated by the relationships with coaches and their peers. For example, a player may be more willing to report an injury when they see their coach equating success to working hard, teamwork and cooperation vs a coach who stresses winning at all cost. Further, most athletes aim to achieve acceptance and respect within the team environment and fear being labeled as soft or weak due to injury. Research has shown that among high-school-aged athletes, underreporting may occur due to

peer acceptance (Ommundsen, Roberts, Lemyre, & Miller, 2005), coaching mindset (Miller, Roberts, & Ommundsen, 2004), or simple lack of injury awareness. In 2013, an incident of second impact syndrome took the life of a 17-year-old female high school rugby player in Ontario, Canada. A coroner's inquest was performed into the nature of her injury, which led to the identification of 49 recommendations for improved concussion awareness and management (Government of Canada, 2016a). In response, Ontario became the first Canadian province to impose concussion legislation in 2016. Rowan's Law, named after the late Rowan Stringer, was established to ensure greater awareness and better treatment for concussion-related injuries. Further, Bill 149 recommends the implementation of a mandatory curriculum for coaches and players to identify and manage concussions (Government of Canada, 2016a). The Government of Canada has recognized the impact of concussion on athletes and public health and has recently provided \$1.4 million in funding to develop and implement a standardized evidence-based approach to preventing, managing and increasing concussion awareness within Canada (Government of Canada, 2016b).

### **The Evolution of Concussion Assessment Tools**

The lack of consensus regarding the definition of a concussion resulted in uncertainty for the diagnostic process and records indicate this was recognized even prior to 1966 (Congress of Neurological Surgeons, 1966). The first consensus statement defining a concussion was proposed by the Committee of Head Injury Nomenclature of the Congress of Neurologic Surgeons (CHINCNS) and was introduced in 1966. The CHINCNS defined concussion as a clinical syndrome characterized by the immediate and transient post-traumatic impairment of neuronal function such as

alteration of consciousness, disturbance of vision or equilibrium due to brainstem involvement (Congress of Neurological Surgeons, 1966). In an evidence-based review of sport-related concussion performed in 2001, the authors acknowledged the definition of concussion in its current form remained unsatisfactory for the sporting community (Johnston et al., 2001). Further, the authors identified twenty-five sport-related concussion grading scales previously used and again determined that none satisfied the validity and practicality needs of the clinician (Johnston et al., 2001). Shortly thereafter, the first International Symposium on Concussion in Sport, held in Vienna, aimed to provide a working document with recommendations for the health and safety of athletes participating in ice hockey, football (soccer), and other sports who suffer from concussive injuries (Aubry et al., 2002). The Concussion in Sport Group (CISG) established a protocol which contained a list of items including; clinical history, evaluation, neuropsychological testing, imaging procedures, research methods, management and rehabilitation, prevention, education, future directions and medical-legal considerations. With the establishment of this protocol, a concussion was defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces (Aubry et al., 2002). This protocol was developed for all individuals involved in the care of athletes such as; doctors, therapists, health professionals, and coaches. This includes athletes of all levels whether recreational, elite, or professional (Aubry et al., 2002). The CISG identified the limitations of the CHINCNS definition established in 1966 as it did not account for many common symptoms of a concussion, nor recognize physical and/or cognitive symptoms caused by minor impacts. The CISG, therefore, proposed a revised definition of concussion

and, in addition, were in unanimous agreement to abandon all prior concussion grading systems (Aubry et al., 2002). In 2004, the same group, with the addition of many more qualified members, held the 2<sup>nd</sup> International Symposium on concussion in Sport in Prague, Czech Republic. The CISG sought to further develop the conceptual understanding of concussions and build on the principles outlined in the original document (McCrory et al., 2005). This updated version established a sideline assessment tool (Sport Concussion Assessment Tool 2), with a pocket-sized summary card for use by clinicians (McCrory et al., 2005). The definition of concussion remained unchanged during the 2004 meeting however; it was noted that concussive symptoms may be prolonged or persistent in some cases post-injury. The CISG did, however, identify a new classification system whereby concussions may be categorized for management purposes as simple or complex (McCrory et al., 2005). This classification terminology was short-lived as it was later abandoned during the 3<sup>rd</sup> International Conference on Concussion in Sport held in Zurich in 2008, where the CISG agreed that the terminology did not fully encompass all aspects of a concussive injury (McCrory et al., 2009). Later, the 4<sup>th</sup> International Conference on Concussion in Sport, held in Zurich in 2012, built on the three previous consensus documents with minor revisions to the definition of concussion and revised the SCAT2 to the Sport Concussion Assessment Tool 3 (SCAT3), the Child SCAT3 (C-SCAT3), and the Concussion Recognition Tool (CRT) for the lay person (McCrory et al., 2013). The SCAT3 is currently the most widely accepted evidence-based sideline assessment tool which has been adopted by many amateur and professional organizations such as World Rugby, the National Football League, the National Hockey League, and the Canadian Football League. Moreover,


several national and provincial injury prevention organizations such as Parachute, the BC Injury Prevention and Research Unit, as well as, professional health organizations such as the Canadian Athletic Therapist Association and Sport Physiotherapist Association have also adopted this tool. The SCAT3 is designed for the youth and adult populations (age 13 and up), which includes; Glasgow Coma Scale (GCS), Maddocks' questions (Maddocks, Dicker, & Saling, 1995), Post-Concussion Symptom Scale, Standardized Assessment of Concussion (McCrea, 2001), neck examination, and a modified Balance Error Scoring System (Furman et al., 2013; McCrory et al., 2013).

As described earlier, there is empirical evidence to suggest that children and adolescents can take longer to recover than adults after a concussion (Beauchamp et al., 2011; Verger et al., 2000). Consequently, there is a need to identify different concussion assessment and management tools for different age groups. Early on it was recognized that the SCAT may not address the requirements of the pediatric population, however, it was agreed that it was suitable for assessing children (age 5-18 years old) for concussion (Aubry et al., 2002). In 2004, there was unanimous agreement that the tool be applied to only those children and adolescent 10 years and older (McCrory et al., 2005). Finally, in 2014, a tool suitable for children (12 and under) C-SCAT3 was established in addition to the SCAT3 and the CRT. There are notable differences between the SCAT3 and the C-SCAT3 to accommodate for the adult/child differences shown in Figures 3 and 4. The differences between the SCAT3 and the C-SCAT3 are noted in Figures 4 and 6.

# SCAT3™

## Sport Concussion Assessment Tool – 3rd Edition

For use by medical professionals only



Name: \_\_\_\_\_ Date/Time of Injury: \_\_\_\_\_ Examiner: \_\_\_\_\_  
Date of Assessment: \_\_\_\_\_

### What is the SCAT3?<sup>1</sup>

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<sup>2</sup>. 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<sup>3</sup>. Pre-season 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?	<input type="checkbox"/> Y <input type="checkbox"/> N
"If so, how long?" _____	
Balance or motor incoordination (stumbles, slow/laboured movements, etc.)?	<input type="checkbox"/> Y <input type="checkbox"/> N
Disorientation or confusion (inability to respond appropriately to questions)?	<input type="checkbox"/> Y <input type="checkbox"/> N
Loss of memory:	<input type="checkbox"/> Y <input type="checkbox"/> N
"If so, how long?" _____	
"Before or after the injury?" _____	
Blank or vacant look:	<input type="checkbox"/> Y <input type="checkbox"/> N
Visible facial injury in combination with any of the above:	<input type="checkbox"/> Y <input type="checkbox"/> N

### 1 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

GCS should be recorded for all athletes in case of subsequent deterioration.

### 2 Maddocks Score<sup>3</sup>

*"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
<b>Maddocks score</b>	<b>0</b>	<b>5</b>

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.**

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**Figure 3.** A depiction of the first page of both the SCAT3 for comparison to the Child SCAT3 shown in Figure 4.

# Child-SCAT3™



## Sport Concussion Assessment Tool for children ages 5 to 12 years

For use by medical professionals only

### What is childSCAT3?

The ChildSCAT3 is a standardized tool for evaluating injured children for concussion and can be used in children aged from 5 to 12 years. It supersedes the original SCAT and the SCAT2 published in 2005 and 2009, respectively. For older persons, ages 13 years and over, please use the SCAT3. The ChildSCAT3 is designed for use by medical professionals. If you are not qualified, please use the Sport Concussion Recognition Tool. Pre-season baseline testing with the ChildSCAT3 can be helpful for interpreting post-injury test scores.

Specific instructions for use of the ChildSCAT3 are provided on page 3. If you are not familiar with the ChildSCAT3, 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 and any reproduction in a digital form require approval by the Concussion in Sport Group.

**NOTE:** The diagnosis of a concussion is a clinical judgment, ideally made by a medical professional. The ChildSCAT3 should not be used solely to make, or exclude, the diagnosis of concussion in the absence of clinical judgment. An athlete may have a concussion even if their ChildSCAT3 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 (like those 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 severe brain injury. If the concussed child displays any of the following, then do not proceed with the ChildSCAT3; instead activate 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
- Persistent vomiting
- Evidence of skull fracture
- Post traumatic seizures
- Coagulopathy
- History of Neurosurgery (eg Shunt)
- Multiple injuries

### Potential signs of concussion?

If any of the following signs are observed after a direct or indirect blow to the head, the child 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:  Y  N  
 "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

---

### 2 Sideline Assessment – child-Maddocks Score<sup>9</sup>

"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)

Where are we at now?	0	1
Is it before or after lunch?	0	1
What did you have last lesson/class?	0	1
What is your teacher's name?	0	1
<b>child-Maddocks score</b>	<b>of 4</b>	

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

**Any child with a suspected concussion should be REMOVED FROM PLAY, medically assessed and monitored for deterioration (i.e., should not be left alone). No child diagnosed with concussion should be returned to sports participation on the day of injury.**

### BACKGROUND

Name: \_\_\_\_\_ Date/Time of Injury: \_\_\_\_\_  
 Examiner: \_\_\_\_\_ Date of Assessment: \_\_\_\_\_  
 Sport/team/school: \_\_\_\_\_  
 Age: \_\_\_\_\_ Gender:  M  F  
 Current school year/grade: \_\_\_\_\_  
 Dominant hand:  right  left  neither  
 Mechanism of Injury ("tell me what happened"): \_\_\_\_\_

**For Parent/carer to complete:**

How many concussions has the child had in the past? \_\_\_\_\_  
 When was the most recent concussion? \_\_\_\_\_  
 How long was the recovery from the most recent concussion? \_\_\_\_\_

Has the child ever been hospitalized or had medical imaging done (CT or MRI) for a head injury?  Y  N

Has the child ever been diagnosed with headaches or migraines?  Y  N

Does the child have a learning disability, dyslexia, ADD/ADHD, seizure disorder?  Y  N

Has the child ever been diagnosed with depression, anxiety or other psychiatric disorder?  Y  N

Has anyone in the family ever been diagnosed with any of these problems?  Y  N

Is the child on any medications? If yes, please list:  Y  N

### 1 Glasgow coma scale (GCS)

<b>Best eye response (E)</b>	
No eye opening	1
Eye opening in response to pain	2
Eye opening to speech	3
Eyes opening spontaneously	4
<b>Best verbal response (V)</b>	
No verbal response	1
Incomprehensible sounds	2
Inappropriate words	3
Confused	4
Oriented	5
<b>Best motor response (M)</b>	
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
<b>Glasgow Coma score (E + V + M)</b>	<b>of 15</b>

GCS should be recorded for all athletes in case of subsequent deterioration.

CHILD-SCAT3 SPORT CONCUSSION ASSESSMENT TOOL 3 | PAGE 1

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**Figure 4.** A depiction of the first page of the Child SCAT3 for comparison to Figure 3. The child Maddocks' questions are slightly different as it requires less information.

## 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

SCAT3 to be done in resting state. Best done 10 or more minutes post exercise.

## SYMPTOM EVALUATION

**3 How do you feel?**  
 "You should score yourself on the following symptoms, based on how you feel now".

	none	mild	moderate	severe			
Headache	0	1	2	3	4	5	6
*Pressure in head*	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
*Don't feel right*	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6

**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

self rated  self rated and clinician monitored  
 clinician interview  self rated with parent input

**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:  
 no different  very different  unsure  N/A

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

**4 Cognitive assessment**  
**Standardized Assessment of Concussion (SAC)\***

**Orientation** (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1

**Orientation score** \_\_\_\_\_ of 5

**Immediate memory**

List	Trial 1	Trial 2	Trial 3	Alternative word list					
elbow	0	1	0	1	0	1	candle	baby	finger
apple	0	1	0	1	0	1	paper	monkey	penny
carpet	0	1	0	1	0	1	sugar	perfume	blanket
saddle	0	1	0	1	0	1	sandwich	sunset	lemon
bubble	0	1	0	1	0	1	wagon	iron	insect

**Total** \_\_\_\_\_

**Immediate memory score total** \_\_\_\_\_ of 15

**Concentration: Digits Backward**

List	Trial 1	Alternative digit list			
4-9-3	0	1	6-2-9	5-2-6	4-1-5
3-8-1-4	0	1	3-2-7-9	1-7-9-5	4-9-6-8
6-2-9-7-1	0	1	1-5-2-8-6	3-8-5-2-7	6-1-8-4-3
7-1-8-4-6-2	0	1	5-3-9-1-4-8	8-3-1-9-6-4	7-2-4-8-5-6

**Total of 4** \_\_\_\_\_

**Concentration: Month in Reverse Order** (1 pt. for entire sequence correct)  
 Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan  0  1

**Concentration score** \_\_\_\_\_ of 5

**5 Neck Examination:**  
 Range of motion \_\_\_\_\_ Tenderness \_\_\_\_\_ Upper and lower limb sensation & strength \_\_\_\_\_  
**Findings:** \_\_\_\_\_

**6 Balance examination**  
 Do one or both of the following tests.  
 Footwear (shoes, barefoot, braces, tape, etc.) \_\_\_\_\_

**Modified Balance Error Scoring System (BESS) testing\***  
 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 gait\***  
 Time (best of 4 trials): \_\_\_\_\_ seconds

**7 Coordination examination**  
**Upper limb coordination**  
 Which arm was tested:  Left  Right  
**Coordination score** \_\_\_\_\_ of 1

**8 SAC Delayed Recall\***  
**Delayed recall score** \_\_\_\_\_ of 5

Figure 5. A depiction of page two of the SCAT3 for comparison to page two of the Child SCAT3 shown in Figure 6.

### SYMPTOM EVALUATION

**3 Child report**

Name: \_\_\_\_\_

	never	rarely	sometimes	often
I have trouble paying attention	0	1	2	3
I get distracted easily	0	1	2	3
I have a hard time concentrating	0	1	2	3
I have problems remembering what people tell me	0	1	2	3
I have problems following directions	0	1	2	3
I daydream too much	0	1	2	3
I get confused	0	1	2	3
I forget things	0	1	2	3
I have problems finishing things	0	1	2	3
I have trouble figuring things out	0	1	2	3
It's hard for me to learn new things	0	1	2	3
I have headaches	0	1	2	3
I feel dizzy	0	1	2	3
I feel like the room is spinning	0	1	2	3
I feel like I'm going to faint	0	1	2	3
Things are blurry when I look at them	0	1	2	3
I see double	0	1	2	3
I feel sick to my stomach	0	1	2	3
I get tired a lot	0	1	2	3
I get tired easily	0	1	2	3

**Total number of symptoms (Maximum possible 20)** \_\_\_\_\_

**Symptom severity score (Maximum possible 20x3=60)** \_\_\_\_\_

self rated     clinician interview     self rated and clinician monitored

### COGNITIVE & PHYSICAL EVALUATION

**5 Cognitive assessment**

**Standardized Assessment of Concussion – Child Version (SAC-C)\***

**Orientation** (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
<b>Orientation score</b>	<b>of 4</b>	

**Immediate memory**

List	Trial 1	Trial 2	Trial 3	Alternative word list	
elbow	0	1	0	1	candle    baby    finger
apple	0	1	0	1	paper    monkey    penny
carpet	0	1	0	1	sugar    perfume    blanket
saddle	0	1	0	1	sandwich    sunset    lemon
bubble	0	1	0	1	wagon    iron    insect
<b>Total</b>					
<b>Immediate memory score total</b>	<b>of 15</b>				

**Concentration: Digits Backward**

List	Trial 1	Alternative digit list			
6-2	0	1	5-2	4-1	4-9
4-9-3	0	1	6-2-9	5-2-6	4-1-5
3-8-1-4	0	1	3-2-7-9	1-7-9-5	4-9-6-8
6-2-9-7-1	0	1	1-5-2-8-6	3-8-5-2-7	6-1-8-4-3
7-1-8-4-6-2	0	1	5-3-9-1-4-8	8-3-1-9-6-4	7-2-4-8-5-6
<b>Total of 5</b>					

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

Sunday-Saturday-Friday-Thursday-Wednesday-Tuesday-Monday	0	1
<b>Concentration score</b>	<b>of 6</b>	

**4 Parent report**

**The child**

	never	rarely	sometimes	often
has trouble sustaining attention	0	1	2	3
is easily distracted	0	1	2	3
has difficulty concentrating	0	1	2	3
has problems remembering what he/she is told	0	1	2	3
has difficulty following directions	0	1	2	3
tends to daydream	0	1	2	3
gets confused	0	1	2	3
is forgetful	0	1	2	3
has difficulty completing tasks	0	1	2	3
has poor problem solving skills	0	1	2	3
has problems learning	0	1	2	3
has headaches	0	1	2	3
feels dizzy	0	1	2	3
has a feeling that the room is spinning	0	1	2	3
feels faint	0	1	2	3
has blurred vision	0	1	2	3
has double vision	0	1	2	3
experiences nausea	0	1	2	3
gets tired a lot	0	1	2	3
gets tired easily	0	1	2	3

**Total number of symptoms (Maximum possible 20)** \_\_\_\_\_

**Symptom severity score (Maximum possible 20x3=60)** \_\_\_\_\_

Do the symptoms get worse with physical activity?  Y  N

Do the symptoms get worse with mental activity?  Y  N

parent self rated     clinician interview     parent self rated and clinician monitored

**Overall rating** for parent/teacher/coach/carer to answer.  
How different is the child acting compared to his/her usual self?

Please circle one response:

<input type="radio"/> no different	<input type="radio"/> very different	<input type="radio"/> unsure	<input type="radio"/> N/A
------------------------------------	--------------------------------------	------------------------------	---------------------------

Name of person completing Parent-report: \_\_\_\_\_

Relationship to child of person completing Parent-report: \_\_\_\_\_

**6 Neck Examination:**

Range of motion    Tenderness    Upper and lower limb sensation & strength

**Findings:** \_\_\_\_\_

**7 Balance examination**

Do one or both of the following tests.

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

**Modified Balance Error Scoring System (BESS) testing\***

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

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

**Tandem gait\***

Time taken to complete one of 4 stae: \_\_\_\_\_ seconds

If child attempted, but unable to complete tandem gait, mark here

**8 Coordination examination**

**Upper limb coordination**

Which arm was tested:  Left  Right

**Coordination score** \_\_\_\_\_ of 1

**9 SAC Delayed Recall\***

**Delayed recall score** \_\_\_\_\_ of 5

Scoring on the ChildSCAT3 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.

**Figure 6.** A depiction of page two of the Child SCAT3 for comparison to Figure 5. Notable differences on page two of the SCAT3 and the C-SCAT3 include 1) the

symptom scale is child-specific with a four-point rating scale instead of a six-point scale, 3) there is a parent rating section for the parent to rate the child's symptoms, 4) the orientation questions do not include time of day, 5) the concentration starts with two reverse digits instead of three, 6) children are asked to recite the days of the week in reverse instead of the months of year in reverse, and finally 7) the Modified Balance Error Scoring System does not include the single leg stance.

The 5<sup>th</sup> International Consensus Conference on Concussion in Sport was held in Berlin in November 2016 where the CISG reviewed the latest literature to revise the gold standard of concussion care, the SCAT3. Numerous authors have challenged the CISG to evaluate the standard of concussion management in a more in-depth manner, emphasizing how concussion should be evaluated as well as developing a more comprehensive set of return to play guidelines. To aid in the advancement of concussion surveillance and management, Raftery et al. (2016) sought to give concussion an operational definition to 1) address the timing of concussion assessment, 2) define how the concussion diagnosis is confirmed or excluded, and 3) the content of each point-in-time assessment. These guidelines, implemented by World Rugby in 2016, are based on the SCAT3 and include a three-step time dependant head injury assessment protocol. The head injury assessments include an initial assessment immediately post injury, a second assessment within three hours of injury, and a third follow-up thirty-six to forty-eight hours post injury. This protocol standardizes sideline and clinical assessments using components of the SCAT3 for head injury assessments one through three, with the addition of a nonspecific cognitive assessment of the teams choice during head injury assessment three (Raftery et al., 2016). A concussion cannot be excluded unless all three assessments have been completed thirty-six to forty-eight hours after injury with normal findings. However, if the symptoms are found to be

unrelated to concussion by a team doctor, a concussion diagnosis can be overturned. Athletes with confirmed concussion status must complete the graduated return to play protocol as set out by the Consensus Statement on Concussion (McCrory et al., 2013; Raftery et al., 2016). This detailed, time dependant assessment protocol may prove useful for future research investigations as it helps to regulate concussion assessment and allows for a more standard documentation for injury surveillance and reporting.

Despite the improvement in our understanding of the phenomenon of concussion and the corresponding evolution of the resulting evaluation tools, there remains a consensus within the research community that a significant amount of research is yet required. Specifically, an important component of concussion evaluation that has not been included within the SCAT3, is the evaluation of vision. With a large portion of the brain's involvement in vision (Van Essen, 2004; Van Essen & Drury, 1997), and the commonality of oculomotor impairments post-concussion (Ciuffreda, Ludlam, & Thiagarajan, 2011), there is a need for an objective measure testing visual performance, beyond the SCAT3 and C-SCAT3, to aid in the identification of concussion.

### **Vision and concussion**

The pathophysiological aspects of concussion and their contributions to post-concussion symptoms have been under review for some time. In the acute concussion, the brain is in a state of metabolic crisis (Giza & Hovda, 2001; Len & Neary, 2011). Autonomic Nervous System dysfunction has been identified as the primary source of symptom exacerbation during exercise post mTBI (Willer & Leddy, 2006). This symptom exacerbation is caused by the uncoupling of the cardiovascular and autonomic nervous

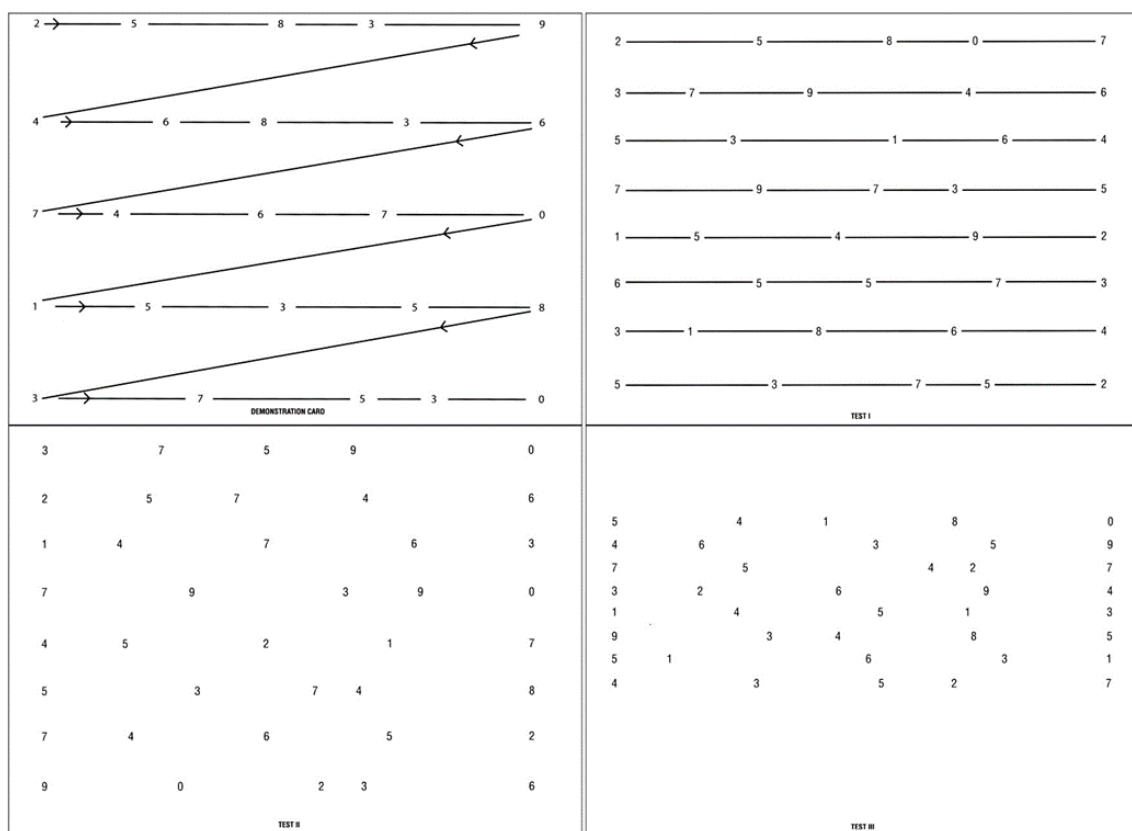
systems (Gall, Parkhouse, & Goodman, 2004). It has been reported that cerebral blood flow has been compromised with mTBI due to impairment of cerebrovascular reactivity. Specifically, cerebral blood flow decreases immediately following mTBI and can remain lowered for extended periods of time dependent on severity (Giza & Hovda, 2001).

In addition to the metabolic crisis, a variety of visual impairments have been reported following a concussion. With 30% of the brain circuitry along with seven of the twelve cranial nerves involved in visual processing (Van Essen, 2004; Van Essen & Drury, 1997), it is reasonable to expect there is a vulnerability within the system to a concussion (Felleman & Van Essen, 1991; Ventura, Balcer, & Galetta, 2014; Ventura, Jancuska, Balcer, & Galetta, 2015). It has been reported that visual problems are seen in nearly 30% of athletes during the first week after injury (Kontos et al., 2012). Some of the visual impairments seen post-concussion include deficits in visual attention, accommodation, convergence, saccades, pursuits, higher order and reading deficits (Barnett & Singman, 2015; Kontos et al., 2016). These problems have been found to derive from damage to the different visual pathways and visual association areas (Barnett & Singman, 2015).

### **King-Devick Test (KDT)**

The KDT is a measure of processing speed, visual tracking, and saccadic eye movements (Vartiainen et al., 2014). It was initially performed to assess saccadic eye movements in reading as it requires the participant to read the numbers aloud from test cards as quickly and as accurately as possible (Oride, Marutani, Rouse, & DeLand, 1986). Shown in Figure 7. The test typically takes between one and two minutes with the final score as the total time required to complete the test in seconds. This test

requires the use of several areas the brain including the dorsolateral prefrontal cortex (rapid number naming), and also tests the use of the brainstem, cerebellum and cerebral cortex (attention, language and reading) (Galetta, Barrett, et al., 2011; Galetta, Brandes, et al., 2011).



**Figure 7. A depiction of the King-Devick Test cards.** The demonstration card is identified top left with subsequent cards I, II, and III.

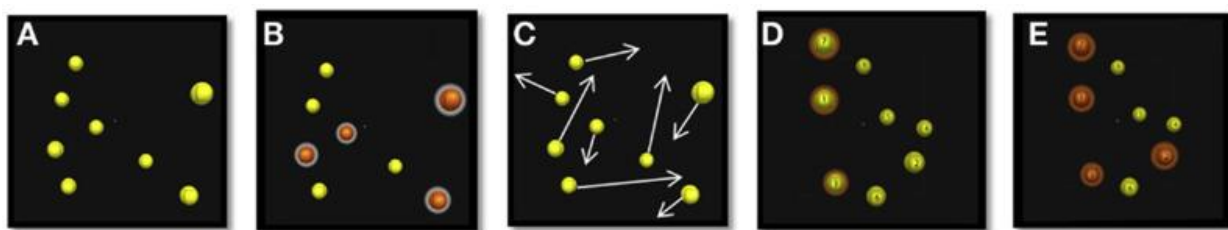
Several studies examined the KDT as a potential concussion screening tool in sports such as football, hockey, soccer, boxing, and rugby (Galetta, Barrett, et al., 2011; Galetta, Brandes, et al., 2011; King, Gissane, et al., 2015; King, Hume, et al., 2015). The KDT has shown high test-retest reliability, with intraclass correlations of 0.97 (95% confidence interval [CI] 0.90, 1.0) between measurements in the absence of concussion

(Galetta, Barrett, et al., 2011; Galetta, Brandes, et al., 2011). Further, research has shown that a worsening of the KDT post-injury test score in relation to the baseline score aids in the identification of concussion (Galetta, Barrett, et al., 2011; Galetta, Brandes, et al., 2011; M. S. Galetta et al., 2013; King, Clark, & Gissane, 2012). Thus, the addition of the KDT to current performance measure increases the ability to detect concussed athletes. However, as previously discussed, ocular motor function such as pursuit, convergence, and accommodation, are not assessed using the KDT, all of which have been implicated in mTBI as important indicators of dysfunction (Capó-Aponte et al., 2012; Ciuffreda et al., 2007). This leads us to consider other possible measures with the abilities to measure visual deficits above and beyond the KDT.

### **Three-dimensional Multiple Object Tracking (3D-MOT)**

The addition of vision testing such as the KDT is an obvious step towards refining sideline and clinical concussion evaluation, yet there remains additional visual-spatial dysfunctions post-concussion that must be evaluated. The multiple object tracking task was initially introduced by Pylyshyn and Storm, (Pylyshyn, 1994; Pylyshyn & Storm, 1988), to evaluate the ability to track multiple elements. 3D-MOT, such as the NeuroTracker™, can be used for performance enhancement, reducing the risk of injury, and used as a baseline reference for return to play post-concussion (Kolb et al., 2011). More recently 3D-MOT has been used to enhance cognitive-perceptual abilities used for sports performance (Parsons et al., 2014; Perico, Tullo, Perrotti, Faubert, & Bertone, 2014). The 3D-MOT is quantitative objective measure eliciting high-level mental resources, such as complex motion integration and working memory, which are known to be affected by concussion (Brosseau-Lachaine et al., 2008; Faubert & Sidebottom,

2012). The technique used in this study requires 1) distributed attention on a separate number of dynamic elements, 2) a large visual field, 3) speed thresholds, and 4) stereoscopy (binocular depth cues) (Faubert & Sidebottom, 2012). This type of task requires higher order cognitive functioning (e.g., dynamic visual attention, working memory, complex motion integration), to correctly process dynamic visual setting. Specifically, 3D-MOT trains sustained, selective, and divided attention, as well as, inhibition, short-term and working memory, and visual information processing speed (Parsons et al., 2014), by tracking four of eight spherical targets as they move through 3D space (Faubert & Sidebottom, 2012), see Figure 8.



**Figure 8. A depiction of the five stages of 3D-MOT using the NeuroTracker™ core mode.** A) Presentation, where eight stimuli are displayed on the viewing screen for the participant. B) Indexation, where four of the stimuli are designated as targets for attention. C) Movement, with all targets presented as a uniform color. D) Identification, where targets are now stationary and assigned a numerical value between one and eight. E) Feedback, where the original targets for the trial are now illuminated to provide feedback to the participant.

The brain is highly plastic and trainable following learning or injury (Faubert & Sidebottom, 2012; Mahncke et al., 2006), for this reason, the brain is adaptable to intensive functional tasks (Draganski & May, 2008). The intelligent staircase procedure embedded in 3D-MOT pushes the participant's speed thresholds for maximal stimulation by eliciting performance just above and below their individual processing threshold (Faubert & Sidebottom, 2012). This process activates relevant regions of

brain such as 1) the visual cortex (ability to see the test), 2) frontal cortex (movement planning, attention, saccades, smooth tracking, convergence), 3) temporal lobes (memory of targets), and 4) parietal lobes (attention, inhibition of distractors) in addition to the seven cranial nerves required for vision (Blumenfeld, 2010). As evidence shows that training 3D-MOT enhances cognitive function by improving attention, visual information processing speed and working memory (Romeas, Guldner, & Faubert, 2016). It is hypothesized that once a stable baseline has been established, any drop from this baseline level may indicate some level of perceptual-cognitive impairment which can aid in the identification of a concussion (Faubert & Sidebottom, 2012). The 3D-MOT gives reliable and objective information on the current perceptual state of the athlete as the ability to track multiple objects has been identified as essential to decision making and anticipatory response in a dynamic sports environment (Smeeton, Williams, Hodges, & Ward, 2005). Further, it has been theorized that the baseline reference of a healthy athlete will provide an objective reference for return to play decisions, therefore reducing the risk of injuries and recurring concussions (Kolb et al., 2011).

The 3D-MOT contains perceptual-cognitive training abilities eliciting mental resources known to be severely affected by concussion (Faubert & Sidebottom, 2012). Based on the facets of the visual system elicited by the 3D-MOT, and its trainability, it is hypothesized that the 3D-MOT may be a strong candidate to aid in the identification of concussion impairments beyond the SCAT3 and KDT. This may prove useful for clinicians when determining return to play/learn status post-concussion.

## Summary

Sports medicine professionals are faced with a significant challenge in the diagnosis of concussion due to the variability in presentation, the elusiveness of symptoms, and inadequate evaluation tools (Giza & Hovda, 2001; McCrory et al., 2013). Extensive research has been performed in an attempt to establish effective sideline and clinical measures to identify and care for concussions, more recently focusing on more complex visual information processing as an additive measure (Alsalaheen et al., 2015; Galetta et al., 2015; Mucha et al., 2014; Oride et al., 1986; Pearce et al., 2015; Ventura et al., 2015). Given the scope of the public health issue, the lack diagnostic tools which capture and identify all impairments of the individual's concussion, and the potential for adverse consequences of an early return to play following sports-related concussions, there is a clear need for objective measures to assess visual perception skills to augment the current gold standard tests to aid in the understanding, diagnosis, and management of sports concussion. Thus, the purpose of this study was to evaluate the 3D-MOT as a potential screening tool which can be an additional measure of cognitive dysfunction post-concussion beyond the SCAT3/C-SCAT3 and KDT to aid healthcare providers with return to play/learn decisions. This study evaluates the extent to which the KDT, and components of the SCAT3/C-SCAT3 specifically immediate memory (IM), coordination (COOR), and delayed recall (DR) (as shown in Figure 4), predict 3D-MOT speed.

## References

- Alla, S., Sullivan, S. J., & McCrory, P. (2012). Defining asymptomatic status following sports concussion: fact or fallacy? *British Journal of Sports Medicine*, *46*(8), 562–9. <http://doi.org/10.1136/bjsm.2010.081299>
- Alsalaheen, B. A., Whitney, S. L., Marchetti, G. F., Furman, J. M., Kontos, A. P., Collins, M. W., & Sparto, P. J. (2015). Relationship between cognitive assessment and balance measures in adolescents referred for vestibular physical therapy after concussion. *Clinical Journal of Sports Medicine*, *26*, 46–52. <http://doi.org/10.1097/JSM.0000000000000185>
- Atkins, E. J., Newman, N. J., & Biousse, V. (2008). Post-traumatic visual loss. *Reviews in Neurological Diseases*, *5*(2), 73–81. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/18660739>
- Aubry, M., Cantu, R., Dvorak, J., Graf-Baumann, T., Johnston, K., Kelly, J., ... Schamasch, P. (2002). Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. *British Journal of Sports Medicine*, *36*(1), 6–10. Retrieved from <http://doi.org/10.1136/bjsm.36.1.6>
- Balasundaram, A. P., Sullivan, J. S., Schneiders, A. G., & Athens, J. (2013). Symptom response following acute bouts of exercise in concussed and non-concussed individuals - a systematic narrative review. *Physical Therapy in Sport*, *14*(4), 253–258. <http://doi.org/10.1016/j.ptsp.2013.06.002>
- Barnett, B. P., & Singman, E. L. (2015). Vision concerns after mild traumatic brain injury. *Current Treatment Options in Neurology*, *17*(5), 1–14. <http://doi.org/10.1007/s11940-014-0329-y>
- BC Injury Research and Prevention Unit. (2016). Concussion statistics across BC Health Authorities among children and youth. Retrieved from <http://www.injuryresearch.bc.ca/injury-insight-concussion-statistics-across-bc-health-authorities-among-children-youth/>
- Beauchamp, M. H., Ditchfield, M., Maller, J. J., Catroppa, C., Godfrey, C., Rosenfeld, J. V., ... Anderson, V. A. (2011). Hippocampus, amygdala and global brain changes 10 years after childhood traumatic brain injury. *International Journal of Developmental Neuroscience*, *29*, 137–43. <http://doi.org/10.1016/j.ijdevneu.2010.12.003>
- Blumenfeld, H. (2010). *Neuroanatomy through clinical cases* (2nd ed.). Sunderland, MA: Sinauer Associates, Inc.
- Brosseau-Lachaine, O., Gagnon, I., Forget, R., & Faubert, J. (2008). Mild traumatic brain injury induces prolonged visual processing deficits in children. *Brain Injury*, *22*(9), 657–668. <http://doi.org/10.1080/02699050802203353>
- Capó-Aponte, J. E., Urosevich, T. G., Temme, L. A., Tarbett, A. K., & Sanghera, N. K. (2012). Visual dysfunctions and symptoms during the subacute stage of blast-induced mild traumatic brain injury. *Military Medicine*, *177*(7), 804–13. Retrieved

from <http://www.ncbi.nlm.nih.gov/pubmed/22808887>

- Ciuffreda, K. J., Kapoor, N., Rutner, D., Suchoff, I. B., Han, M. E., & Craig, S. (2007). Occurrence of oculomotor dysfunctions in acquired brain injury: A retrospective analysis. *Optometry*, *78*(4), 155–61. <http://doi.org/10.1016/j.optm.2006.11.011>
- Ciuffreda, K. J., Ludlam, D., & Thiagarajan, P. (2011). Oculomotor diagnostic protocol for the mTBI population. *Journal of Optometry*, *82*(2), 61–63. <http://doi.org/10.1016/j.optm.2010.11.011>
- Collins, M. W., Grindel, S. H., Lovell, M. R., Dede, D. E., Moser, D. J., Phalin, B. R., ... Indelicato, P. (1999). Relationship between concussion and neuropsychological performance in college football players. *Journal of American Medical Association*, *282*(10), 964–970. Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/10485682>
- Collins, M. W., Kontos, A. P., Reynolds, E., Murawski, C. D., & Fu, F. H. (2014). A comprehensive, targeted approach to the clinical care of athletes following sport-related concussion. *Knee Surgery, Sports Traumatology, Arthroscopy*, *22*(2), 235–46. <http://doi.org/10.1007/s00167-013-2791-6>
- Colvin, A. C., Mullen, J., Lovell, M. R., West, R. V., Collins, M. W., & Groh, M. (2009). The role of concussion history and gender in recovery from soccer-related concussion. *The American Journal of Sports Medicine*, *37*(9), 1699–1704. <http://doi.org/10.1177/0363546509332497>
- Congress of Neurological Surgeons. (1966). Congress of Neurological Surgeons Committee on head injury nomenclature: glossary of head injury. *Clinical Neurosurgery*, *12*, 386–394.
- Covassin, T., Elbin, R. J., Harris, W., Parker, T., & Kontos, A. (2012). The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *The American Journal of Sports Medicine*, *40*(6), 1303–1312. <http://doi.org/10.1177/0363546512444554>
- Draganski, B., & May, A. (2008). Training-induced structural changes in the adult human brain. *Behavioural Brain Research*, *192*(1), 137–42. <http://doi.org/10.1016/j.bbr.2008.02.015>
- Elbin, R. J., Kontos, A. P., Kegel, N., Johnson, E., Burkhart, S., & Schatz, P. (2013). Individual and combined effects of LD and ADHD on computerized neurocognitive concussion test performance: evidence for separate norms. *Archives of Clinical Neuropsychology*, *28*(5), 476–484. <http://doi.org/10.1093/arclin/act024>
- Faubert, J. (2013). Professional athletes have extraordinary skills for rapidly learning complex and neutral dynamic visual scenes. *Scientific Reports*, *3*(1154), 1–3. <http://doi.org/10.1038/srep01154>
- Faubert, J., & Sidebottom, L. (2012). Perceptual-cognitive training of athletes. *Journal of Clinical Sport Psychology*, *6*(1), 85–102. <http://doi.org/10.1123/jcsp.6.1.85>
- Faul, M., Xu, L., Wald, M. M., & Coronado, V. G. (2010). *Traumatic brain injury in the United States: emergency department visits, hospitalizations, and deaths 2002-*

2006. *Centers for Disease Control and Prevention, National Center for Injury Prevention and Control*. Atlanta, GA. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/23630120>

- Felleman, D. J., & Van Essen, D. C. (1991). Distributed hierarchical processing in the primate cerebral cortex. *Cerebral Cortex*, *1*(1), 1–47.
- Field, A. (2013). The beast of bias. In *Discovering statistics using IBM SPSS statistics*. (4th ed., pp. 163–212). Thousand Oaks, California: SAGE Publications.
- Field, Collins, M. W., & Lovell, M. R. (2003). Does age play a role in recovery from sports related concussions? A comparison of high school and collegiate athletes. *Journal of Pediatrics*, *142*(5), 546–553. <http://doi.org/10.1067/mpd.2003.190>
- Furman, G. R., Lin, C.-C., Bellanca, J. L., Marchetti, G. F., Collins, M. W., & Whitney, S. L. (2013). Comparison of the balance accelerometer measure and balance error scoring system in adolescent concussions in sports. *The American Journal of Sports Medicine*, *41*(6), 1404–1410. <http://doi.org/10.1177/0363546513484446>
- Gaetz, M. B., & Iverson, G. L. (2009). Sex differences in self-reported symptoms after aerobic exercise in non-injured athletes: implications for concussion management programmes. *British Journal of Sports Medicine*, *43*, 508–13. <http://doi.org/10.1136/bjism.2008.051748>
- Galetta, K. M., Barrett, J., Allen, M., Madda, F., Delicata, D., Tennant, A. T., ... Balcer, L. J. (2011). The King-Devick test as a determinant of head trauma and concussion in boxers and MMA fighters. *Neurology*, *76*, 1456–62. <http://doi.org/10.1212/WNL.0b013e31821184c9>
- Galetta, K. M., Brandes, L. E., Maki, K., Dziemianowicz, M. S., Laudano, E., Allen, M., ... Balcer, L. J. (2011). The King-Devick test and sports-related concussion: study of a rapid visual screening tool in a collegiate cohort. *Journal of the Neurological Sciences*, *309*, 34–9. <http://doi.org/10.1016/j.jns.2011.07.039>
- Galetta, K. M., Morganroth, J., Moehringer, N., Mueller, B., Hasanaj, L., Webb, N., ... Balcer, L. J. (2015). Adding vision to concussion testing: a prospective study of sideline testing in youth and collegiate athletes. *Journal of Neuro-Ophthalmology*, *35*, 235–241. <http://doi.org/10.1097/WNO.0000000000000226>
- Galetta, M. S., Galetta, K. M., McCrossin, J., Wilson, J. A., Moster, S., Galetta, S. L., ... Master, C. L. (2013). Saccades and memory: baseline associations of the King-Devick and SCAT2 SAC tests in professional ice hockey players. *Journal of the Neurological Sciences*, *328*, 28–31. <http://doi.org/10.1016/j.jns.2013.02.008>
- Gall, B., Parkhouse, W., & Goodman, D. (2004). Heart rate variability of recently concussed athletes at rest and exercise. *Medicine & Science in Sports & Exercise*, *36*(8), 1269–1274. <http://doi.org/10.1249/01.MSS.0000135787.73757.4D>
- Giza, C. C., & Hovda, D. A. (2001). The neurometabolic cascade of concussion. *Journal of Athletic Training*, *36*(3), 228–235.
- Government of Canada. (2016a). An Act to establish an advisory committee to make

recommendations made in the inquest into the death of Rowan Stringer. *Bill 149, 1st Session, 41st Legislature, 65 Elizabeth II.*

- Government of Canada. (2016b). Government takes action, 1–4. Retrieved from [http://news.gc.ca/web/article-en.do?mthd=index&ctr.page=1&nid=1140669&\\_ga=1.62594348.1295253183.1475672455](http://news.gc.ca/web/article-en.do?mthd=index&ctr.page=1&nid=1140669&_ga=1.62594348.1295253183.1475672455)
- Guskiewicz, K. (2003). Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA concussion study. *The Journal of the American Medical Association, 290*(19), 2549–2555. <http://doi.org/10.1001/jama.290.19.2549>
- Guskiewicz, K., Weaver, N. L., Padua, D. a, & Garrett, W. E. (2000). Epidemiology of concussion in collegiate and high school football players. *The American Journal of Sports Medicine, 28*, 643–650. <http://doi.org/10.1177/28.suppl>
- Heitger, M. H., Jones, R. D., Macleod, A. D., Snell, D. L., Frampton, C. M., & Anderson, T. J. (2009). Impaired eye movements in post-concussion syndrome indicate suboptimal brain function beyond the influence of depression, malingering or intellectual ability. *Brain : A Journal of Neurology: A Journal of Neurology, 132*, 2850–70. <http://doi.org/10.1093/brain/awp181>
- Hunt, T., & Asplund, C. (2010). Concussion assessment and management. *Clinics in Sports Medicine, 29*(1), 5–17, table of contents. <http://doi.org/10.1016/j.csm.2009.09.002>
- IBM Corporation. (2013). Statistical Processing Software for the Social Sciences. Armonk, NY: IBM Corporation.
- Iverson, G. L., Gaetz, M., Lovell, M. R., & Collins, M. W. (2004). Cumulative effects of concussion in amateur athletes. *Brain Injury : [BI], 18*(5), 433–43. <http://doi.org/10.1080/02699050310001617352>
- Iverson, G. L., & Lange, R. T. (2003). Examination of “postconcussion-like” symptoms in a healthy sample. *Applied Neuropsychology, 10*(3), 137–144. [http://doi.org/10.1207/S15324826AN1003\\_02](http://doi.org/10.1207/S15324826AN1003_02)
- James, S. (Director & P., & Sheridan, B. (Producer). (2012). *Head Games [Motion picture]*. USA.
- Jennett, B., & Bond, M. (1975). Assessment of outcome after severe brain damage: A practical scale. *The Lancet, 305*(7905), 480–484. [http://doi.org/doi:10.1016/S0140-6736\(75\)92830-5](http://doi.org/doi:10.1016/S0140-6736(75)92830-5)
- Johnston, K. M., McCrory, P., Mohtadi, N. G., & Meeuwisse, W. (2001). Evidence-based review of sport-related concussion: clinical science. *Clinical Journal of Sport Medicine, 11*, 150–159. <http://doi.org/10.1097/00042752-200107000-00005>
- King, D., Clark, T., & Gissane, C. (2012). Use of a rapid visual screening tool for the assessment of concussion in amateur rugby league: A pilot study. *Journal of the Neurological Sciences, 320*, 16–21. <http://doi.org/10.1016/j.jns.2012.05.049>

- King, D., Gissane, C., Hume, P. A., & Flaws, M. (2015). The King–Devick test was useful in management of concussion in amateur rugby union and rugby league in New Zealand. *Journal of the Neurological Sciences*, *351*, 58–64. <http://doi.org/10.1016/j.jns.2015.02.035>
- King, D., Hume, P., Gissane, C., & Clark, T. (2015). Use of the King-Devick test for sideline concussion screening in junior rugby league. *Journal of the Neurological Sciences*, *357*, 75–79. <http://doi.org/10.1016/j.jns.2015.06.069>
- Kolb, J., Beauchamp, P., & Faubert, J. (2011). Visual perception training: cutting edge psychophysics and 3D technology applied to sport science. *CIRCUit*, 1–14.
- Kontos, A. P., Elbin, R. J., Lau, B., Simensky, S., Freund, B., French, J., & Collins, M. W. (2013). Posttraumatic migraine as a predictor of recovery and cognitive impairment after sport-related concussion. *The American Journal of Sports Medicine*, *41*(7), 1497–504. <http://doi.org/10.1177/0363546513488751>
- Kontos, A. P., Elbin, R. J., Schatz, P., Covassin, T., Henry, L., Pardini, J., & Collins, M. W. (2012). A revised factor structure for the post-concussion symptom scale: baseline and postconcussion factors. *The American Journal of Sports Medicine*, *40*(10), 2375–2384. <http://doi.org/10.1177/0363546512455400>
- Kontos, A. P., Sufrinko, A., Elbin, R. J., Puskar, A., & Collins, M. W. (2016). Reliability and associated risk factors for performance on the Vestibular/Ocular Motor Screening (VOMS) tool in healthy collegiate athletes. *The American Journal of Sports Medicine*, *44*(6), 1400–1406. <http://doi.org/10.1177/0363546516632754>
- Kuczynski, A., Crawford, S., Bodell, L., Dewey, D., & Barlow, K. M. (2013). Characteristics of post-traumatic headaches in children following mild traumatic brain injury and their response to treatment: a prospective cohort. *Developmental Medicine and Child Neurology*, *55*(7), 636–41. <http://doi.org/10.1111/dmcn.12152>
- Laker, S. R. (2015). Sports-Related Concussion. *Current Pain and Headache Reports*, *19*, 41. <http://doi.org/10.1007/s11916-015-0510-3>
- Landesman, P. (Director), Scott, R. (Producer), Scott, G. (Producer), Wolthoff, D. (Producer), Shuman, L. (Producer), & Cantillon, E. (Producer). (2015). *Concussion*. USA: Columbia Pictures. Retrieved from <http://www.nejm.org.ezproxy.library.uvic.ca/doi/pdf/10.1056/NEJMcp064645>
- Langlois, J. a, Rutland-Brown, W., & Wald, M. M. (2006). The epidemiology and impact of traumatic brain injury: a brief overview. *The Journal of Head Trauma Rehabilitation*, *21*(5), 375–378. <http://doi.org/00001199-200609000-00001> [pii]
- Legault, I., Allard, R., & Faubert, J. (2013). Healthy older observers show equivalent perceptual-cognitive training benefits to young adults for multiple object tracking. *Frontiers in Psychology*, *4*, 323. <http://doi.org/10.3389/fpsyg.2013.00323>
- Legault, I., & Faubert, J. (2012). Perceptual-cognitive training improves biological motion perception: evidence for transferability of training in healthy aging. *Neuroreport*, *23*(8), 469–73. <http://doi.org/10.1097/WNR.0b013e328353e48a>

- Len, T. K., & Neary, J. P. (2011). Cerebrovascular pathophysiology following mild traumatic brain injury. *Clinical Physiology and Functional Imaging*, 31(2), 85–93. <http://doi.org/10.1111/j.1475-097X.2010.00990.x>
- Leong, D. F., Balcer, L. J., Galetta, S. L., Liu, Z., & Master, C. L. (2014). The King-Devick test as a concussion screening tool administered by sports parents. *The Journal of Sports Medicine and Physical Fitness*, 54(1), 70–77.
- Leong, D. F., Ventura, R. E., & Steven, L. (2015). The King-Devick test of rapid number naming for concussion detection: meta-analysis and systematic review of the literature. *Concussion*, 1–15. <http://doi.org/10.2217/cnc.15.8>
- Levitt, H. (1971). Transformed up-down methods in psychoacoustics. *The Journal of the Acoustical Society of America*, 49(2B), 467. <http://doi.org/10.1121/1.1912375>
- Maddocks, D., Dicker, G., & Saling, M. (1995). The assessment of orientation following concussion in athletes. *Clinical Journal of Sports Medicine*, 5(1), 32–35.
- Mahncke, H. W., Connor, B. B., Appelman, J., O.N., A., Hardy, J. L., Wood, R. A., ... Merzenich, M. . (2006). Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, control study. *National Academy of Sciences*, 103(33), 12523–12528.
- Marinides, Z., Galetta, K. M., Andrews, C. N., Wilson, J. A., Herman, D. C., Robinson, C. D., ... Clugston, J. R. (2014). Vision testing is additive to the sideline assessment of sports-related concussion. *Neurology Clinical Practice*, 1–10. <http://doi.org/10.1212/CPJ.0000000000000060>
- Master, C. L., Scheiman, M., Gallaway, M., Goodman, A., Robinson, R. L., Master, S. R., & Grady, M. F. (2016). Vision diagnoses are common after concussion in adolescents. *Clinical Pediatrics*, 55(3), 260–267. <http://doi.org/10.1177/0009922815594367>
- Mccaffrey, M. A., Mihalik, J. P., Crowell, D. H., Shields, E. W., & Guskiewicz, K. (2007). Measurement of head impacts in collegiate football players: clinical measures of concussion after high- and low-magnitude impacts. *Neurosurgery*, 61(6), 1236–1243. <http://doi.org/10.1227/01.NEU.0000280153.11614.69>
- McCrea, M. (2001). Standardized mental status assessment of sports concussion. *Clinical Journal of Sport Medicine*, 11(3), 176–181. Retrieved from <http://ovidsp.tx.ovid.com/sp-3.13.1a/ovidweb.cgi?QS2=434f4e1a73d37e8cf1a676fd57658e8af87366de14fce6bd67d5c4234f982c4a6f2562f2d00cf06891b705f8e9224ed93579e0f1f3c31b6b8de7bf31c614f5b6a6c7dd48e5e0cbc0176ca59fd80d94b0f8715e2125b510b681de4c954d0e50adb3a5cf6cb7>
- McCrory, P. (2001). What's in a name? *British Journal of Sports Medicine*, 35, 285–287. <http://doi.org/10.1136/bjism.35.5.285-a>
- McCrory, P., Johnston, K., Meeuwisse, W., Aubry, M., Cantu, R., Dvorak, J., ... Schamasch, P. (2005). Summary and agreement statement of the 2nd International

- Conference on Concussion in Sport, Prague 2004. *British Journal of Sports Medicine*, 39(4), 196–204. <http://doi.org/10.1136/bjsm.2005.018614>
- McCrory, P., Meeuwisse, W. H., Aubry, M., Cantu, B., Dvorák, J., Echemendia, R. J., ... Turner, M. (2013). Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *British Journal of Sports Medicine*, 47(5), 250–8. <http://doi.org/10.1136/bjsports-2013-092313>
- McCrory, P., Meeuwisse, W., Johnston, K., Dvorak, J., Aubry, M., Molloy, M., & Cantu, R. (2009). Consensus statement on concussion in sport: the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *British Journal of Sports Medicine*, 43(Suppl 1), i76-84. <http://doi.org/10.1136/bjsm.2009.058248>
- Miller, B. W., Roberts, G. C., & Ommundsen, Y. (2004). Effect of motivational climate on sportspersonship among competitive youth male and female football players. *Scandinavian Journal of Medicine & Science in Sports*, 14, 193–202. <http://doi.org/10.1046/j.1600-0838.2003.00320.x>
- Morrish, J., & Carey, S. (2013). *Concussions in Canada*. Parachute. Toronto, ON. Retrieved from [www.parachutecanada.org/active-and-safe](http://www.parachutecanada.org/active-and-safe)
- Mucha, A., Collins, M. W., Elbin, R. J., Furman, J. M., Troutman-Enseki, C., DeWolf, R. M., ... Kontos, A. P. (2014). A brief Vestibular/Ocular Motor Screening (VOMS) assessment to evaluate concussions: preliminary findings. *The American Journal of Sports Medicine*, 42(10), 2479–86. <http://doi.org/10.1177/0363546514543775>
- National Center for Injury Prevention and Control. (2003). *Report to congress on mild traumatic brain injury in the United States: steps to prevent a serious public health problem*. Centers for Disease Control and Prevention, National Center for Injury Prevention and Control. Atlanta, GA. Retrieved from <http://www.cdc.gov/traumaticbraininjury/pdf/mtbireport-a.pdf%5Cnpapers2://publication/uuid/C2643C39-C5DE-40A2-A290-A3D04BB6F7BC>
- Ommundsen, Y., Roberts, G. C., Lemyre, P.-N., & Miller, B. W. (2005). Peer relationships in adolescent competitive soccer: associations to perceived motivational climate, achievement goals and perfectionism. *Journal of Sports Sciences*, 23(9), 977–989. <http://doi.org/10.1080/02640410500127975>
- Oride, M. K., Marutani, J. K., Rouse, M. W., & DeLand, P. N. (1986). Reliability study of the Pierce and King-Devick Saccade tests. *American Journal of Optometry and Physiological Optics*, 63(6), 419–24. <http://doi.org/DOI: 10.1097/00006324-198606000-00005>
- Parsons, B., Magill, T., Boucher, A., Zhang, M., Zogbo, K., Berube, S., ... Faubert, J. (2014). Enhancing cognitive function using perceptual-cognitive training. *Clinical EEG and Neuroscience*, 1–11. <http://doi.org/10.1177/1550059414563746>
- Pearce, K. L., Sufrinko, A., Lau, B. C., Henry, L., Collins, M. W., & Kontos, A. P. (2015). Near point of convergence after a sport-related concussion: measurement reliability

- and relationship to neurocognitive impairment and symptoms. *The American Journal of Sports Medicine*, 43(12), 3055–61. <http://doi.org/10.1177/0363546515606430>
- Pellman, E. J., Lovell, M. R., Viano, D. C., & Casson, I. R. (2006). Concussion in professional football: Recovery of NFL and high school athletes assessed by computerized neuropsychological testing - Part 12. *Neurosurgery*, 58(2), 263–272. <http://doi.org/10.1227/01.NEU.0000200272.56192.62>
- Perico, C., Tullo, D., Perrotti, K., Faubert, J., & Bertone, A. (2014). The effect of feedback on 3D multiple object tracking performance and its transferability to other attentional tasks. *Journal of Vision*, 14(10), 357–357. <http://doi.org/10.1167/14.10.357>
- Pinto, P. S., Meoded, A., Poretti, A., Tekes, A., & Huisman, T. A. G. M. (2012). The unique features of traumatic brain injury in children. Review of the characteristics of the pediatric skull and brain, mechanisms of trauma, patterns of injury, complications, and their imaging findings-part 1. *Journal of Neuroimaging*, 22(2), e1–e17. <http://doi.org/10.1111/j.1552-6569.2011.00690.x>
- Putukian, M., Raftery, M., Guskiewicz, K., Herring, S., Aubry, M., Cantu, R. C., & Molloy, M. (2013). Onfield assessment of concussion in the adult athlete. *British Journal of Sports Medicine*, 47(5), 285–88. <http://doi.org/10.1136/bjsports-2013-092158>
- Pylyshyn, Z. (1994). Some primitive mechanisms of spatial attention. *Cognition*, 50(1–3), 363–384. Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/8039369>
- Pylyshyn, Z., & Storm, R. W. (1988). Tracking multiple independent targets: evidence for a parallel tracking mechanism. *Spatial Vision*, 3(3), 179–197.
- Raftery, M., Kemp, S., Patricios, J., Makdissi, M., & Decq, P. (2016). It is time to give concussion an operational definition: a 3-step process to diagnose (or rule out) concussion within 48 h of injury: World Rugby guideline. *British Journal of Sports Medicine*, 50(11), 642–643. <http://doi.org/10.1136/bjsports-2016-095959>
- Rapport, M. D., Orban, S. A., Kofler, M. J., & Friedman, L. M. (2013). Do programs designed to train working memory, other executive functions, and attention benefit children with ADHD? A meta-analytic review of cognitive, academic, and behavioral outcomes. *Clinical Psychology Review*, 33(8), 1237–1252. <http://doi.org/10.1016/j.cpr.2013.08.005>
- Rizzo, J. R., Hudson, T. E., Dai, W., Desai, N., Yousefi, A., Palsana, D., ... Rucker, J. C. (2016). Objectifying eye movements during rapid number naming: Methodology for assessment of normative data for the King-Devick test. *Journal of the Neurological Sciences*, 362, 232–239. <http://doi.org/10.1016/j.jns.2016.01.045>
- Romeas, T., Guldner, A., & Faubert, J. (2016). 3D-Multiple Object Tracking training task improves passing decision-making accuracy in soccer players. *Psychology of Sport and Exercise*, 22(2016), 1–9. <http://doi.org/10.1016/j.psychsport.2015.06.002>

- Ruijs, M. B. M., Keyser, A., & Gabreëls, F. J. M. (1994). Clinical neurological trauma parameters as predictors for neuropsychological recovery and long-term outcome in paediatric closed head injury: a review of the literature. *Clinical Neurology and Neurosurgery*, *96*(4), 273–283. [http://doi.org/10.1016/0303-8467\(94\)90114-7](http://doi.org/10.1016/0303-8467(94)90114-7)
- Schatz, P., Moser, R. S., Covassin, T., & Karpf, R. (2011). Early indicators of enduring symptoms in high school athletes with multiple previous concussions. *Neurosurgery*, *68*(6), 1562–1567. <http://doi.org/10.1227/NEU.0b013e31820e382e>
- Smeeton, N. J., Williams, A. M. M., Hodges, N. J. N. J., & Ward, P. (2005). The relative effectiveness of various instructional approaches in developing anticipation skill. *Journal of Experimental Psychology*, *11*(2), 98–110. <http://doi.org/DOI:10.1037/1076-898X.11.2.98>
- Teadsale, G., & Jennett, B. (1974). Assessment of coma and impaired consciousness: A practical scale. *The Lancet*, *304*(7872), 81–84. [http://doi.org/http://dx.doi.org/10.1016/S0140-6736\(74\)91639-0](http://doi.org/http://dx.doi.org/10.1016/S0140-6736(74)91639-0)
- Van Essen, D. C. (2004). Organization of visual areas in macaque and human cerebral cortex. *The Visual Neurosciences*, *1*, 507–521. <http://doi.org/10.1.1.218.5723>
- Van Essen, D. C., & Drury, H. A. (1997). Structural and functional analyses of human cerebral cortex using a surface-based atlas. *Journal of Neuroscience*, *17*(18), 7079–7102.
- Vartanian, O., Coady, L., & Blackler, K. (2016). 3D Multiple Object Tracking boosts working memory Span: implications for cognitive training in military populations. *Military Psychology*, 1–8. <http://doi.org/10.1037/mil0000125>
- Vartiainen, M. V., Holm, A., Peltonen, K., Luoto, T. M., Iverson, G. L., & Hokkanen, L. (2014). King-Devick test normative reference values for professional male ice hockey players. *Scandinavian Journal of Medicine & Science in Sports*, *25*(3), e327–330. <http://doi.org/10.1111/sms.12307>
- Ventura, R. E., Balcer, L. J., & Galetta, S. L. (2014). The neuro-ophthalmology of head trauma. *The Lancet. Neurology*, *13*(10), 1006–1016. [http://doi.org/10.1016/S1474-4422\(14\)70111-5](http://doi.org/10.1016/S1474-4422(14)70111-5)
- Ventura, R. E., Jancuska, J. M., Balcer, L. J., & Galetta, S. L. (2015). Diagnostic tests for concussion. *Journal of Neuro-Ophthalmology*, *35*, 73–81. <http://doi.org/10.1097/WNO.0000000000000223>
- Verger, K., Junqué, C., Jurado, M. A. a, Tresserras, P., Bartumeus, F., Nogués, P., & Poch, J. M. M. (2000). Age effects on long-term neuropsychological outcome in paediatric traumatic brain injury. *Brain Injury : [BI]*, *14*(6), 495–503. <http://doi.org/10.1080/026990500120411>
- Willer, B., & Leddy, J. J. (2006). Management of concussion and post-concussion syndrome. *Current Treatment Options in Neurology*, *8*(5), 415–426. <http://doi.org/10.1007/s11940-006-0031-9>
- Williams, V. B., & Danan, I. J. (2016). A historical perspective on sports concussion:

where we have been and where we are going. *Current Pain and Headache Reports*, 20(6), 43. <http://doi.org/10.1007/s11916-016-0569-5>

Zakzanis, K. K., & Yeung, E. (2011). Base rates of post-concussive symptoms in a nonconcussed multicultural sample. *Archives of Clinical Neuropsychology*, 26(5), 461–5. <http://doi.org/10.1093/arclin/acr021>

## Chapter 2: Manuscript to be submitted to Journal of Neurological Sciences

The Extent to which the King-Devick Test and Sport Concussion Assessment Tool 3

Predict 3-Dimensional Multiple Object Tracking Speed

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**Objective:** To determine the extent to which aspects of the Sport Concussion Assessment Tool 3 (SCAT3) or Child SCAT3 (C-SCAT3), and the King-Devick Test (KDT) predict Three-Dimensional Multiple Object Tracking (3D-MOT) speed.

**Participants:** A sample of 304 healthy, non-concussed participants with a sporting history (101 females, 203 males) ranging in age from 7-29 years (mean age = 16.05 +/- 4.36) were included in the analysis. **Methods:** Participants completed the SCAT3, KDT and 3D-MOT in a single visit. **Data Analysis:** A regression analysis was performed to determine the extent to which aspects of the SCAT3 (immediate memory (IM), coordination (COOR), delayed recall (DR)), and the KDT predicted 3D-MOT speed.

**Results:** Using the stepwise method, it was found that KDT, DR and COOR explain a significant amount of the variance in the speed of the 3D-MOT ( $F(3, 256) = 11.82, p < .000$  with an  $R^2 = .12$ ). The analysis shows that KDT (Beta = -0.01,  $p < .000$ ), DR (Beta = 0.07,  $p < .02$ ), and COOR (Beta = .23,  $p < .03$ ), were significant predictors of 3D-MOT speed. **Conclusions:** This study suggests that the KDT, DR, and COOR significantly account for 12% of the 3D-MOT scores, however, there is a large portion of variability unaccounted for by the SCAT3 or C-SCAT3 and KDT. This shows that 3D-MOT likely accounts for central cognitive functions above and beyond the SCAT3 or C-SCAT3 and KDT. Future studies should examine this relationship at baseline, post-injury, and through concussion recovery. This could provide valuable information to better inform clinicians responsible for making return to play determinations. **Keywords:** Concussion, Mild Traumatic Brain Injury, 3D-MOT, King-Devick Test, Sport Concussion Assessment Tool 3, Child Sport Concussion Assessment Tool 3.

## 1. Introduction

Sport-related concussions have become recognized as a major public health concern with an estimated incidence of over 4 million per year (McCrory et al., 2013). Concussions are complex and difficult injuries to manage. There are currently few objective and quantitative measures that have been validated scientifically which can be applied when diagnosing patients. Further, sideline evaluations for a concussion can be difficult because of the variability, subjectivity, and elusiveness of symptoms (Putukian et al., 2013). To address the complexity of concussion diagnosis and care, a group of experts established the Sport Concussion Assessment Tool 3 (SCAT3), the Child Sport Concussion Assessment Tool3 (C-SCAT3), and the Pocket Sport Concussion Assessment Tool in 2012 (McCrory et al., 2013). These tools are intended to provide gold standard apparatuses to assist parents, coaches and medical professionals with the diagnosis of concussion. The SCAT3/C-SCAT3 are composed of a subjective self-symptom report, a brief neuropsychological test battery that assesses attention and memory function, along with balance and coordination (McCrory et al., 2013). Despite the progress made in the development of these tests, there remain notable limitations due to the subjective nature of the self-symptom reporting (McCrory et al., 2013) and lack of an operational definition (Raftery et al., 2016), which can lead to false negative diagnoses (Marinides et al., 2014). More recently, the Government of Canada has provided \$1.4 million in research funding to develop and implement an evidence-based approach to preventing, managing and increasing awareness surrounding concussions in Canada. As currently there is no consistent approach to concussion care, the Canadian Government elected Parachute Canada, the leading injury prevention group,

to standardize concussion care based on the evidence resulting from the CISG's 5th International Consensus Conference on Concussion in Sport in 2016.

As researchers continue to strive for enhanced approaches to facilitate the diagnosis and documentation of concussions, there are opportunities for improvement in objective quantifiable measurements of concussive events. One such area of opportunity for providing a more enhanced quantitative assessment is the use of visual spatial tasks as diagnostic indicators. Surprisingly, while it is known that sports concussions commonly affect visual pathways, current standards do not include visual performance testing as part of standard protocol. The King-Devick Test (KDT) has gained recent attention due to the objective nature and speed at which it can be administered (under two minutes). Further, the test is unique in that a layperson (parent or coach), can successfully perform the test. This has increased the popularity and usage of the KDT (Leong, Balcer, Galetta, Liu, & Master, 2014). The KDT test incorporates the visual system and demands the ability to perform rapid number naming using saccadic eye movements, as well as language function and attention, which in addition to cognitive and balance testing, adds a critical dimension to the diagnosis of concussion (Leong, Ventura, & Steven, 2015; Marinides et al., 2014). Recent studies have shown that an individual's performance on the KDT correlates and objectively measures suboptimal brain function post-concussion (Galetta et al., 2015) at a high degree of sensitivity and specificity (Leong et al., 2014). As the complex visual circuitry in the brain involves cognitive processing (memory, attention, and language), which have been shown to be affected by concussion, the KDT is well suited to assist in the assessment of concussion (Leong et al., 2015).

Unfortunately, the KDT alone does not evaluate all aspects of this complex cognitive/visual system. The three-dimensional multiple object tracking program (3D-MOT), has gained traction within the sporting environment as a performance training tool and has demonstrated the ability to improve cognitive functions in a healthy population (Parsons et al., 2014). The 3D-MOT is a computerized testing method which requires individuals to divide their attention visually across multiple moving targets and distractors and provides clinicians with objective data that may aid in the detection of suboptimal brain function (Faubert, 2013; Faubert & Sidebottom, 2012; Legault, Allard, & Faubert, 2013). Given that similar aspects of cognitive function (i.e. dynamic visual attention, working memory, and complex motion integration) are known to be affected by sport-related concussions (Faubert & Sidebottom, 2012), 3D-MOT could add to the voracity of concussion testing beyond the SCAT3/C-SCAT3 and KDT.

Given that 3D-MOT has proven useful in sports performance training (Romeas et al., 2016) and has also shown promise as an additional reference for post-concussion readiness (Faubert & Sidebottom, 2012), this study sought to determine the extent to which the gold standard of care (SCAT3/C-SCAT3) and another current concussion measure KDT predicted 3D-MOT scores. A regression analysis was performed to determine the extent to which components of the SCAT3/C-SCAT3 (immediate memory, coordination and delayed recall), KDT predict 3D-MOT scores during pre-season baseline testing in an athletic population. It was hypothesized that immediate memory, coordination, delayed recall, and KDT will significantly predict 3D-MOT performance at baseline. This is important because 3D-MOT may be able to identify

impairments post-concussion above and beyond the SCAT3 and the KDT providing healthcare professionals more information to make better decisions for return to play.

## **2. Methods**

### **2.1 Participants**

The current study reports on a sample of 304 participants (101 females, 203 male) between the ages of 7-29, who volunteered for this study. All participants completed a single visit of testing in an assigned research space at the University of Victoria or identified locations on the Vancouver Island. Participants were recruited from Greater Victoria, British Columbia, Canada, between September 2012 and June 2016 through the local middle and high schools, sporting communities, posters, and word of mouth. Participants were included in the study if 1) they were older than 7 years of age, 2) were not currently concussed or experiencing concussion-like symptoms within the last three months, and 3) did not report having any health conditions affecting their vision or report being color blind. Ethics approval was obtained from the Human Research Ethics Board at the University of Victoria in accordance with the Canadian Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (Certificate 12-271).

### **2.2 Equipment and procedures**

All participants completed a short medical history questionnaire to provide descriptive data for age, gender, concussion history and sporting history. Parental input was necessary to complete the forms for children and youth. Each participant also completed the Sport Concussion Assessment Tool 3 (SCAT3) or the Child SCAT3 (C-SCAT3) based on their age. Although participants completed the entire SCAT3

assessment, for this study, only the immediate memory (IM), coordination (COOR), and delayed recall (DR) task scores were considered. In addition to the SCAT3, the participant also completed the King-Devick Test and a 3D-MOT test with standardized procedures accompanying the tools.

### 2.2.1 Sport Concussion Assessment Tool 3 (SCAT3)

The first task evaluated was the test of immediate memory whereby the participants were asked to repeat the same list of words back to the tester in any order shown in Table 1. The words were read at a rate of one per second and three trials were completed. A point was awarded for each correct response.

Table 1.

#### *A Depiction of the Task of Immediate Memory*

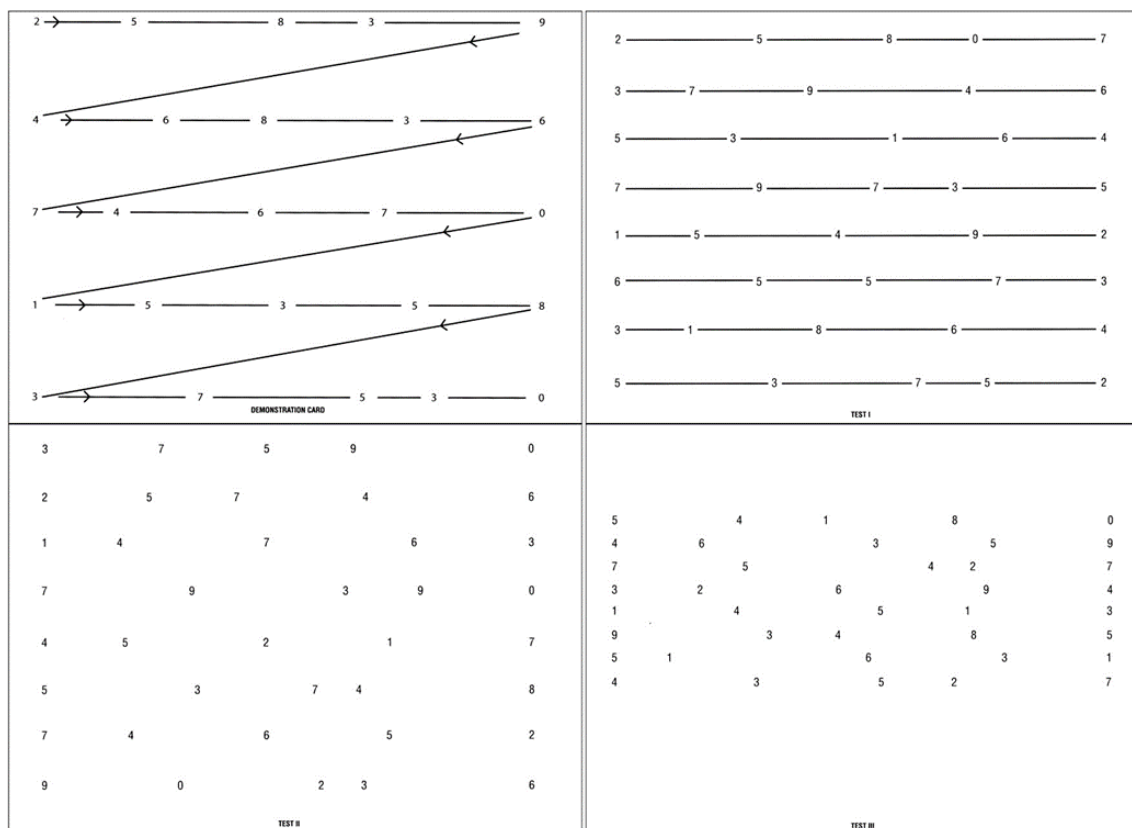
<b>List</b>	<b>Trial 1</b>		<b>Trial 2</b>		<b>Trial 3</b>		<b>Alternative word list</b>		
<b>Elbow</b>	0	1	0	1	0	1	Candle	Baby	Finger
<b>Apple</b>	0	1	0	1	0	1	Paper	Monkey	Penny
<b>Carpet</b>	0	1	0	1	0	1	Sugar	Perfume	Blanket
<b>Saddle</b>	0	1	0	1	0	1	Sandwich	Sunset	Lemon
<b>Bubble</b>	0	1	0	1	0	1	Wagon	Iron	Insect
<b>Total of 4</b>									

The next task was an upper limb coordination task (COOR) where the participants were asked to sit comfortably in a chair and perform five successive finger to nose repetitions using their index finger to touch the tip of the nose and then return to the starting position, as quickly and as accurately as possible. A point was awarded if the participant

touched their nose and fully extended their elbow during the five repetitions in less than four seconds. Finally, the participants were asked to recall and recite the words from the list that was read to them earlier. A point for each correct response was recorded.

### **2.2.2 King-Devick Test (KDT)**

The KDT, shown in Figure 9, was administered using a standardized procedure provided with the test. The participants completed two trials where they read three test cards aloud, sequentially, as quickly and as accurately as possible. The participants were instructed to read from left to right and upon completion of the row to move down a line to continue to read from left to right until they finished the card. For each trial, corrective lenses or glasses were worn as required and the participants sat in a chair holding the test card at a normal reading distance. The tester instructed the participant to turn to test card one and begin reading the numbers when they were ready. The tester began timing as soon as the participant read aloud the first number and stopped the timer as soon as the participant completed the test card. The examiner then recorded the time on the score sheet and instructed the participant to turn over to test card two and begin reading as soon as they are ready. The examiner began timing test card two as soon as the participant began reading numbers stopping when the test card was completed. The process was repeated for test card three. The tester monitored the test card recording any omission, addition or reversal errors. An error was not counted if the participant corrected themselves during the test. The cumulative time to complete all three test cards were recorded and the test was then repeated a second time with the fastest time of the two tests used as their baseline time.

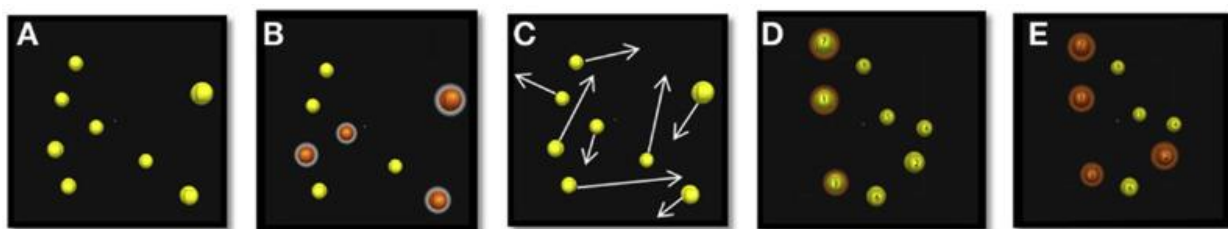


**Figure 9.** A depiction of the King-Devick Test cards. The demonstration card is identified top left with subsequent cards I, II, and III.

### 2.2.3 Three-Dimensional Multiple Object Tracking (3D-MOT)

Finally, three sessions of 20 trials of the 3D-MOT tool were performed using the standard instructions. For each trial, participants sat upright, 1.6 m away, with their eyes positioned at the center of a 60-inch 3D high definition television screen. First, the participant was presented with eight identical yellow balls randomly placed on a television screen (presentation phase). Second, four of the eight balls turned red and were highlighted with a white halo for two seconds to identify the targets to track (indexation phase). Third, the four target balls returned to yellow and all eight balls moved and bounced around the screen for eight seconds (movement phase). Fourth,

the balls stopped moving and the participant was asked to identify the target balls originally identified (identification phase). Last, the participant was given feedback about the correct target balls for three seconds (feedback phase). A depiction of the phases of the NeuroTracker™ Core mode can be found in Figure 10. Speed thresholds, the outcome variable of interest, were calculated using a 1-up 1-down staircase procedure (Levitt, 1971), such that after each correct response (i.e., four target balls identified accurately) the speed of the balls was increased by .05 log and after each incorrect response the speed of the balls was decreased by .05 log. The process results in a threshold criterion of 50%. After 20 trials, the speed threshold was calculated as the mean speed threshold from the last four inversions.



**Figure 10. A depiction of the five stages of 3D-MOT using the NeuroTracker™ core mode.** A) Presentation, where eight stimuli are displayed on the viewing screen for the participant. B) Indexation, where four of the stimuli are designated as targets for attention. C) Movement, with all targets presented as a uniform color. D) Identification, where targets are now stationary and assigned a numerical value between one and eight. E) Feedback, where the original targets for the trial are now illuminated to provide feedback to the participant.

### 2.3 Statistical Analysis

Data was entered into Statistical Package for the Social Sciences, Version 22 (SPSS-22; (IBM Corporation, 2013)) and double checked by visual inspection; 2) missing data values were identified, inspected and corrected where appropriate; and 3) errors in data entry (i.e., typographical errors, values outside of possible range for

variable) were identified by running frequencies and descriptive analyses and corrected manually. A modified Windsor procedure was implemented where the smallest and largest values were replaced with the value two standard deviations from the mean (Field, 2013). A multiple regression was conducted to determine the extent to which the 3D-MOT is predicted by IM, COOR, DR, and KDT. All statistical analyses were conducted using SPSS-22.

### **3. Results**

#### **3.1 Demographics**

Participant characteristics are presented in Table 2. There were 304 participants (101 females, 203 male) between the ages of 7-29 years old with an average age 16.05 years (SD = 4.36), (Skewness = 0.14, Kurtosis = 0.28), who volunteered for this study. Most the participants were participating in a sport with hockey (37.3%), soccer (24.8%), rugby (24.4%), basketball (7.6%), and lacrosse (2.3%), being the main sports. Only 115 (37.8%) of the participants had a history of concussion but none within that past three months.

Table 2.

*Characteristics of Participants*

<b>Characteristic</b>	<b>Mean (SD)</b>	<b>N</b>	<b>%</b>
Age	16.05 (4.36)	304	
Gender			
Male		203	66.8
Female		101	33.2
History of mTBI			
No		115	37.8
Yes		189	62.2

*Notes:* M=mean, SD=standard deviation

### 3.2 Test Scores

The means and standard deviations of all test scores are shown in Table 3. The Immediate Memory task is scored out of fifteen based on the number of words the participant recalls during the three trials. Coordination is scored as zero (not completed) or one (completed) based on the participant's ability to perform the task during one trial. Delayed recall is scored out of five based on the number of words they recall. KDT is based on the fastest trial time (in seconds) of the two trials completed. The 3D-MOT speed was calculated using the built-in staircase method where the mean speed threshold from the last four inversions was used.

Table 3.

*Means and Standard Deviations at Baseline*

<b>Test</b>	<b>N</b>	<b>M</b>	<b>SD</b>
Immediate Memory (/15)	270	14.12	(.87)
Coordination (/1)	270	0.80	(.40)
Delayed Recall (/5)	270	4.27	(.94)
King-Devick Test (in seconds)	299	59.48	(13.77)
3-Dimensional Multi-Object Tracking (Log)	280	0.92	(.47)

Notes: M=mean, SD=standard deviation

A multiple linear regression was calculated to determine the extent to which the 3D-MOT scores can be predicted by KDT, IM, DR, and COOR. The assumptions of multivariate regression were tested and corrections were applied as needed. Using the stepwise method, it was found that KDT, DR, and COOR explain a significant amount of the variance in the speed of the 3D-MOT ( $F(3, 256) = 11.82, p < .000$  with an  $R^2$  of .12. Participant's predicted 3D-MOT speed is equal to  $1.05 - .01 \text{ KDT} + .07 \text{ DR} + .23 \text{ COOR}$ , where KDT is measured in seconds, DR is measured in units between 0-5, and COOR is measured as 1 = successful, 0 = not successful. The analysis shows that KDT (Beta = -0.01,  $p < .000$ ), DR (Beta = 0.07,  $p < .02$ ), and COOR (Beta = .23,  $p < .03$ ), were significant predictors of 3D-MOT scores. The coefficients for the explanatory variables are tabulated in Table 4.

Table 4.

*Coefficients of Linear Regression*

<b>Model</b>		<b>B</b>	<b>SE B</b>	<b>β</b>	<b>T</b>
1	3D-MOT	1.56	0.10		15.59
	King-Devick Test	-0.01	.00	-.30*	-4.86
2	3D-MOT	1.36	0.14		9.49
	King-Devick Test	-0.01	0.00	-.31*	-5.19
	Delayed Recall	0.07	0.03	.15**	2.51
3	3D-MOT	1.05	0.19		5.68
	King-Devick Test	-.01	0.00	-.28*	-4.43
	Delayed Recall	0.07	0.03	.14**	2.44
	Coordination	0.23	0.11	.13**	2.15

Note: Dependent Variable = 3D-MOT,  $R^2 = .08$ ,  $p < .001$ , for Model 1,  $R\Delta = .02$ ,  $p < .05$  for Model 2,  $R\Delta = .02$ ,  $p < .05$  for Model 3. \* $p < .001$ , \*\*  $p < .05$ .

Model 1 looks at the percentage of the variability of 3D-MOT scores explained by the KDT task alone. Model 1 shows that the KDT accounts for the largest amount of variability between all the Models with 8% of the variability of 3D-MOT  $R^2 = .08$ ,  $p < .001$ . Model 2 and Model 3 add equal amounts of variability of 3D-MOT scores with Model 2 showing that DR, in addition to the KDT, significantly adds to the variability of 3D-MOT with an  $R\Delta = .02$ ,  $p < .05$  and Model 3 including KDT, DR, and COOR, with an  $R\Delta = .02$ ,  $p < .05$ . Therefore, Model 1 appears to be the strongest model showing that KDT has the most predictability for 3D-MOT in this study. Whereas, Immediate memory does not show any predictability in either of the 3 models.

#### 4. Discussion

This study sought to determine the extent to which 3D-MOT speed could be predicted by SCAT3 or C-SCAT3 and the KDT. Interestingly, IM was not shown to be a significant predictor for all 3 Models. This is somewhat surprising since the 3D-MOT, IM, COOR, DR, and KDT all share closely related anatomical brain structures (Blumenfeld, 2010; M. S. Galetta et al., 2013; Kolb et al., 2011). That said, our study shows that KDT, COOR and DR significantly predict 3D-MOT speed. More importantly, the findings of my study suggest that 3D-MOT likely accounts for global integration of central cognitive functions above and beyond the SCAT3 and KDT confirming to the need for multiple assessment tools in the diagnosis of concussion. The MOT task requires activation of significantly large mental resources and requires efficient integration across several domains of neurological functions within the brain. Working memory is essential for good executive functioning, affecting how well an individual can process complex thinking for immediate decision making. The 3D-MOT elicits several attentional systems that are critical components of executive functions, as well as strongly eliciting working memory resources. These working memory functions are dynamic and crucial for everyday life as well as academic performance. The 3D-MOT task elicits memory and recall (manipulating information; accessing stored facts), activation, arousal, and effort (getting started; finishing work), impulsivity and monitoring (thinking before acting or speaking; self-awareness), analysis and organized thinking (breaking down information and complex problem solving), shifting, inhibiting (stopping and changing activities, transitioning attention) (Rapport, Orban, Kofler, & Friedman, 2013).

It is surprising that the aspects of the SCAT3 are less accounted for in the models. As working memory is elicited by the 3D-MOT, it was expected that those aspects of the SCAT3 involving memory would account for a larger amount of the variability of the 3D-MOT scores. However, the nature of the baseline testing likely plays a large role in the lack of variability in scoring at baseline. As the majority of the athletes tested at baseline achieved 15/15 for IM and 5/5 for DR, the baseline scoring of IM and DR do not account for the population of athletes that can remember more than 5 words immediately and with delayed recall. This ceiling effect could limit the SCAT3 ability to truly capture a baseline score. Further, there may be some added benefits to the use of the 3D-MOT as compared to tests such as the KDT and SCAT3. The DR, IM, and the KDT are all static measurements containing ceiling effects. The implications of these ceiling effects are such that the resolution of self-reported symptoms and the return to baseline scores of the DR, IM, and KDT may permit false assumptions of full recovery. Brosseau-Lachaine et al. (2008), found that complex perceptual deficits persisted up to three months post mTBI (Brosseau-Lachaine et al., 2008). For those individuals with protracted recoveries, the 3D-MOT likely provides useful information, beyond the capabilities of the KDT, DR, and COOR, which may decrease the chances of a premature return to sport.

This study was strengthened by the standardized methods and procedures which allows for reproducibility of this study. Further the large sample size allows for more representative of the population, limiting the influence of outliers or extreme observations.

There are several limitations that must be considered when interpreting the findings of this study. First, the assumptions for the linear regression were not all met so the results are not generalizable outside this dataset. Second, the IM and DR test scores were based on a fixed interval scoring system and COOR is based on a dichotomous scoring system. All three tests did not allow for a normally distributed data set based on their scoring systems. Moreover, the age distribution for this data set had a multimodal distribution which could also affect the interpretation of the statistical analysis. However, the large sample size gives strength in the absence of assumptions being met for this analysis. This study also relied heavily on previous research showing that 3D-MOT elicits higher order processing as this study did directly measure for these attributes. Finally, clinical researchers have suggested that a concussion may magnify pre-existing conditions, resulting in specific clinical trajectories (Collins, Kontos, Reynolds, Murawski, & Fu, 2014). These pre-existing risk factors can be categorized as primary which exists prior to the injury, and secondary which occur post injury (Collins et al., 2014). These primary risk factors are associated with increased deficits and longer recovery times post-concussion. Risk factors include; sex (Colvin et al., 2009; Covassin, Elbin, Harris, Parker, & Kontos, 2012), age (Covassin et al., 2012; Field, Collins, & Lovell, 2003; Pellman, Lovell, Viano, & Casson, 2006), neurodevelopmental conditions (eg. ADHD, LD) (Collins et al., 1999; Elbin et al., 2013), migraine history (personal or family) (Kontos et al., 2013), mental health and concussion history (Schatz, Moser, Covassin, & Karpf, 2011). The current study did not evaluate the relationships of pre-existing risk factors that may influence both baseline and post-injury performance on

tests. This information is necessary to discern the effects of injuries from pre-existing deficits.

Future studies should consider controlling for risk factors such as; sex, age (Covassin et al., 2012; Field et al., 2003; Pellman et al., 2006), neurodevelopmental conditions (eg. ADHD, LD), migraine history (personal or family) (Kontos et al., 2013), mental health and concussion history (Schatz et al., 2011), which are important details for clinical outcome, when comparing baseline and post-injury scores. This will add to the depth of the study and will aid in determining the validity of the 3D-MOT within concussion management. Examining the relationship between abnormal baseline 3D-MOT and concussion outcomes may help researchers gain insight into the potential link between risk factors and poor outcomes after a concussion.

## **5. Conclusion**

Concussions are a significant public health concern within the sporting community. This study was one of the first to investigate the extent to which 3D-MOT is predicted by IM, COOR, DR, and the KDT. The findings of this study, showing that KDT, DR, and COOR predict 3D-MOT speed, indicate that 3D-MOT possess the capability to assess visual impairments above and beyond the KDT and the SCAT3. The research presented in this thesis will add to existing literature that suggests the 3D-MOT is a promising concussion assessment tool. Moreover, these findings provide important clinical considerations for the sports medicine professionals reinforcing the need for multiple tools for conducting a comprehensive concussion evaluation. Moving forward, researchers should examine the role of the 3D-MOT post-concussion in athletic and non-athletic populations. Additionally, studies should consider including the role of

modifiers and control for risk factors when comparing baseline and post-injury scores to better understand these relationships.

**Disclaimer**

There are no known conflicts of interest to report.

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## References

- Blumenfeld, H. (2010). *Neuroanatomy through clinical cases* (2nd ed.). Sunderland, MA: Sinauer Associates, Inc.
- Brosseau-Lachaine, O., Gagnon, I., Forget, R., & Faubert, J. (2008). Mild traumatic brain injury induces prolonged visual processing deficits in children. *Brain Injury*, 22(9), 657–668. <http://doi.org/10.1080/02699050802203353>
- Collins, M. W., Grindel, S. H., Lovell, M. R., Dede, D. E., Moser, D. J., Phalin, B. R., ... Indelicato, P. (1999). Relationship between concussion and neuropsychological performance in college football players. *Journal of American Medical Association*, 282(10), 964–970. Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/10485682>
- Collins, M. W., Kontos, A. P., Reynolds, E., Murawski, C. D., & Fu, F. H. (2014). A comprehensive, targeted approach to the clinical care of athletes following sport-related concussion. *Knee Surgery, Sports Traumatology, Arthroscopy*, 22(2), 235–46. <http://doi.org/10.1007/s00167-013-2791-6>
- Colvin, A. C., Mullen, J., Lovell, M. R., West, R. V., Collins, M. W., & Groh, M. (2009). The role of concussion history and gender in recovery from soccer-related concussion. *The American Journal of Sports Medicine*, 37(9), 1699–1704. <http://doi.org/10.1177/0363546509332497>
- Covassin, T., Elbin, R. J., Harris, W., Parker, T., & Kontos, A. (2012). The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *The American Journal of Sports Medicine*, 40(6), 1303–1312. <http://doi.org/10.1177/0363546512444554>
- Elbin, R. J., Kontos, A. P., Kegel, N., Johnson, E., Burkhart, S., & Schatz, P. (2013). Individual and combined effects of LD and ADHD on computerized neurocognitive concussion test performance: evidence for separate norms. *Archives of Clinical Neuropsychology*, 28(5), 476–484. <http://doi.org/10.1093/arclin/act024>
- Faubert, J. (2013). Professional athletes have extraordinary skills for rapidly learning complex and neutral dynamic visual scenes. *Scientific Reports*, 3(1154), 1–3. <http://doi.org/10.1038/srep01154>
- Faubert, J., & Sidebottom, L. (2012). Perceptual-cognitive training of athletes. *Journal of Clinical Sport Psychology*, 6(1), 85–102. <http://doi.org/10.1123/jcsp.6.1.85>
- Field, A. (2013). The beast of bias. In *Discovering statistics using IBM SPSS statistics*. (4th ed., pp. 163–212). Thousand Oaks, California: SAGE Publications.
- Field, Collins, M. W., & Lovell, M. R. (2003). Does age play a role in recovery from sports related concussions? A comparison of high school and collegiate athletes. *Journal of Pediatrics*, 142(5), 546–553. <http://doi.org/10.1067/mpd.2003.190>
- Galetta, K. M., Morganroth, J., Moehringer, N., Mueller, B., Hasanaj, L., Webb, N., ... Balcer, L. J. (2015). Adding vision to concussion testing: a prospective study of sideline testing in youth and collegiate athletes. *Journal of Neuro-Ophthalmology*,

35, 235–241. <http://doi.org/10.1097/WNO.0000000000000226>

- Galetta, M. S., Galetta, K. M., McCrossin, J., Wilson, J. A., Moster, S., Galetta, S. L., ... Master, C. L. (2013). Saccades and memory: baseline associations of the King-Devick and SCAT2 SAC tests in professional ice hockey players. *Journal of the Neurological Sciences*, 328, 28–31. <http://doi.org/10.1016/j.jns.2013.02.008>
- IBM Corporation. (2013). *Statistical Processing Software for the Social Sciences*. Armonk, NY: IBM Corporation.
- Kolb, J., Beauchamp, P., & Faubert, J. (2011). Visual perception training: cutting edge psychophysics and 3D technology applied to sport science. *CIRCUIT*, 1–14.
- Kontos, A. P., Elbin, R. J., Lau, B., Simensky, S., Freund, B., French, J., & Collins, M. W. (2013). Posttraumatic migraine as a predictor of recovery and cognitive impairment after sport-related concussion. *The American Journal of Sports Medicine*, 41(7), 1497–504. <http://doi.org/10.1177/0363546513488751>
- Legault, I., Allard, R., & Faubert, J. (2013). Healthy older observers show equivalent perceptual-cognitive training benefits to young adults for multiple object tracking. *Frontiers in Psychology*, 4, 323. <http://doi.org/10.3389/fpsyg.2013.00323>
- Leong, D. F., Balcer, L. J., Galetta, S. L., Liu, Z., & Master, C. L. (2014). The King-Devick test as a concussion screening tool administered by sports parents. *The Journal of Sports Medicine and Physical Fitness*, 54(1), 70–77.
- Leong, D. F., Ventura, R. E., & Steven, L. (2015). The King-Devick test of rapid number naming for concussion detection: meta-analysis and systematic review of the literature. *Concussion*, 1–15. <http://doi.org/10.2217/cnc.15.8>
- Levitt, H. (1971). Transformed up-down methods in psychoacoustics. *The Journal of the Acoustical Society of America*, 49(2B), 467. <http://doi.org/10.1121/1.1912375>
- Marinides, Z., Galetta, K. M., Andrews, C. N., Wilson, J. A., Herman, D. C., Robinson, C. D., ... Clugston, J. R. (2014). Vision testing is additive to the sideline assessment of sports-related concussion. *Neurology Clinical Practice*, 1–10. <http://doi.org/10.1212/CPJ.0000000000000060>
- McCrory, P., Meeuwisse, W. H., Aubry, M., Cantu, B., Dvorák, J., Echemendia, R. J., ... Turner, M. (2013). Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *British Journal of Sports Medicine*, 47(5), 250–8. <http://doi.org/10.1136/bjsports-2013-092313>
- Parsons, B., Magill, T., Boucher, A., Zhang, M., Zogbo, K., Berube, S., ... Faubert, J. (2014). Enhancing cognitive function using perceptual-cognitive training. *Clinical EEG and Neuroscience*, 1–11. <http://doi.org/10.1177/1550059414563746>
- Pellman, E. J., Lovell, M. R., Viano, D. C., & Casson, I. R. (2006). Concussion in professional football: Recovery of NFL and high school athletes assessed by computerized neuropsychological testing - Part 12. *Neurosurgery*, 58(2), 263–272. <http://doi.org/10.1227/01.NEU.0000200272.56192.62>

- Putukian, M., Raftery, M., Guskiewicz, K., Herring, S., Aubry, M., Cantu, R. C., & Molloy, M. (2013). Onfield assessment of concussion in the adult athlete. *British Journal of Sports Medicine*, 47(5), 285–88. <http://doi.org/10.1136/bjsports-2013-092158>
- Raftery, M., Kemp, S., Patricios, J., Makdissi, M., & Decq, P. (2016). It is time to give concussion an operational definition: a 3-step process to diagnose (or rule out) concussion within 48 h of injury: World Rugby guideline. *British Journal of Sports Medicine*, 50(11), 642–643. <http://doi.org/10.1136/bjsports-2016-095959>
- Rapport, M. D., Orban, S. A., Kofler, M. J., & Friedman, L. M. (2013). Do programs designed to train working memory, other executive functions, and attention benefit children with ADHD? A meta-analytic review of cognitive, academic, and behavioral outcomes. *Clinical Psychology Review*, 33(8), 1237–1252. <http://doi.org/10.1016/j.cpr.2013.08.005>
- Romeas, T., Guldner, A., & Faubert, J. (2016). 3D-Multiple Object Tracking training task improves passing decision-making accuracy in soccer players. *Psychology of Sport and Exercise*, 22(2016), 1–9. <http://doi.org/10.1016/j.psychsport.2015.06.002>
- Schatz, P., Moser, R. S., Covassin, T., & Karpf, R. (2011). Early indicators of enduring symptoms in high school athletes with multiple previous concussions. *Neurosurgery*, 68(6), 1562–1567. <http://doi.org/10.1227/NEU.0b013e31820e382e>

### Chapter 3. Conclusion and Summary

Concussions are a significant public concern within the sporting community. This study was one of the first to investigate the extent to which 3D-MOT is predicted by IM, COOR, DR, and the KDT. The findings of this study, showing that KDT, DR, and COOR have predictive validity of the 3D-MOT, indicate that 3D-MOT may possess the capability to assess visual capabilities above and beyond the KDT and the SCAT3. The research presented in this thesis will add to existing literature that suggests the 3D-MOT is a promising concussion assessment tool. Moreover, these findings provide important clinical considerations for the sports medicine professionals reinforcing the need for multiple tools for conducting a comprehensive concussion evaluation. Moving forward, researchers should examine the role of the 3D-MOT post-concussion in athletic and non-athletic populations. Additionally, studies should consider including the role of modifiers and control for risk factors when comparing baseline and post-injury scores to better understand these relationships.

## Appendix A – Participant Consent Form

PARTICIPANT NUMBER: \_\_\_\_\_

Division of Medical Sciences  
University of Victoria

*Participant Consent Form***The Vancouver Island Concussion Project – NeuroTracker Study**

You refers to "you or your child"

**Participants Selection**

You have been invited to participate in a study entitled the "Vancouver Island Concussion Project – NeuroTracker study" that is being conducted by Dr. Brian Christie. You are being asked to participate in this study because you either 1) are at high risk for concussion (e.g., hockey, rugby, soccer, have a history of multiple concussions), 2) have had a recent concussion, or 3) have been asked to complete multiple object tracking (MOT) and/or neurocognitive testing as part of a return to play program. Please note that participation is voluntary, that you are under no obligation to participate in this study, and that should you experience a concussion, the tests used in our research laboratory are not intended to take the place of a proper evaluation by your doctor.

Dr. Christie, Ph.D. is a faculty member in the Division of Medical Sciences at the University of Victoria and you may contact him by phone (250)472-4244 or email [brcrain64@uvic.ca](mailto:brcrain64@uvic.ca) should you have further questions. This research is being funded by the Canadian Institute for Health Research and the Canada Foundation for Innovation.

**Purpose and Objectives**

We are interested in learning more about how children, adolescents and adults recover after a concussion. The purpose of this research project is to examine how useful multiple object tracking and related visual spatial tasks are in monitoring recovery following concussion in children, adolescents, and adults. To achieve this, testing will be conducted with individuals before and/or after a concussion. There is a limited research on recovery following concussion, especially in the developing brain, and researchers of the Vancouver Island Concussion Project are interested in learning more. This work will also examine how effective using MOT and visual spatial tools can be in helping parents, teachers, trainers and coaches, and health professionals determine when an individual has recovered from concussion and can return to their usual activities (e.g., physical activity, school/work). This is a research study and individuals who experience a concussion should see a medical doctor for advice/clearance regarding return to sport and other activities.

**Importance of this Research**

Concussions are a form of mild traumatic brain injury. Any blow to the head, face, neck or to the body) that causes a sudden shaking or jarring of the brain inside the skull may cause a concussion. Concussions can affect how an individual thinks and may cause a variety of symptoms (e.g., headaches, dizziness, poor balance). Although there are many tools available for managing concussion, most concussion management programs are not evidence-based and have little to no research to help support their use. As a result, oftentimes concussions are mismanaged. Research on the use of MOT and related visual-spatial testing before and/or after a concussion will help create comprehensive evidence-based concussion management programs to fill this gap. Ultimately, the goal of this Vancouver Island Concussion Project is to improve the diagnosis and management of concussions and to develop a tool box of validated strategies for evidence-based concussion management.

PARTICIPANT NUMBER: \_\_\_\_\_

**What is involved?**

You will complete baseline and/or post-injury testing. If you have not completed baseline testing, you will still be invited to do post-injury testing.

**Baseline Testing:**

1. You will complete an intake form and a brief standardized tool for evaluating concussions. At this testing session, you will complete 1 session of MOT testing on the NeuroTracker program. For this session, you will be required to sit in a chair in front of a large computer. On a large screen you will see 8 yellow-colored balls, 4 of which will turn red and then will turn back to yellow. You will be instructed to track the 4 balls that changed color. Once the balls have stopped moving, you will be asked to identify the balls that had previously changed to red. The balls will be numbered and you will be required to identify which balls they tracked using the numbers below the balls. You will also complete related visual spatial testing, a simple test of reaction time. If you are under age 18 years old, you and your parents will be asked to fill out questionnaires about symptoms you (or your child) are experiencing and how your parents (or you as a parent) respond to these symptoms. Total time commitment of this first session is approximately 50 minutes. At one month after this first session, you will be emailed a link to an online survey which again asks about the symptoms you/your child has been experiencing and how you/your parent responds to these symptoms. All testing is non-invasive.
2. If your MOT scores have not reached a plateau at the first session, you will be requested to complete an additional session(s) on the NeuroTracker program using the above protocol. Individuals will be invited to complete up to 5 baseline sessions (15 trials). Potential time commitment will be 30 minutes to 2.5 hours over several weeks.

**Post-Injury Testing:**

1. Following a head injury, and with your consent, you will be requested to be re-tested using the same protocol explained above.
2. You are asked to come in for testing on 24-72 hours following a concussion – the sooner, the better. We will re-test you every few days until symptoms resolve. The first post-concussion NeuroTracker assessment will take 45 minutes and additional sessions will take about 25-30 minutes. Total time commitment will vary but should be about 3-4 hours spread across several weeks to a month.
3. Return to play and other activities will be decided on by your family physician. Any test results collected as a part of this research study can be made available to your physician upon request.

**Inconvenience**

Participation in this study should cause little inconvenience to you/your child. However, we are asking for you to schedule time for you/your child to be tested, which may cause a slight inconvenience to you/your child.

**Risks**

There are no known or anticipated risks to you/your child by participating in this research.

**Benefits**

Concussions are common in children, youth and athlete populations, and as such are a major public health concern. Establishing best practice guidelines developed through research to help direct the

2

PARTICIPANT NUMBER: \_\_\_\_\_

timing, intensity and duration of post-injury care is important. This research program focuses on validating MOT and visual spatial tools that may help provide definitive guidelines on diagnosis, management and recovery of concussions. It may also help determine the amount of time it takes for a concussed individual to return to their baseline. This work will potentially generate knowledge on the degree of concussion sustained by an individual and their rate of recovery.

#### **Voluntary Participation**

Your participation in this research must be completely voluntary. If you participate, you may withdraw at any time without any consequences or any explanation. If you withdraw from the study data will be used only if you give permission.

#### **On-going Consent**

To make sure that you continue to consent to participate in this research, we will schedule all appointments well in advance and provide you with a summary of dates and times. You will initial and date and on-going consent form at the beginning of each session.

Subsequent to any head injury, it will be up to you to contact us to determine the best time for you to start post-injury sessions. We will work together to develop a schedule of testing that will be acceptable for both parties. Our preferred minimum follow-up testing schedule for anyone suffering a concussion is 1, 3, 5, 7, 14, and 28 days post-concussion. This strict timeline is not mandatory, but will greatly assist our research on post-concussion recovery.

#### **Anonymity**

In terms of protecting your anonymity, a number will be assigned to you so that names will not be used. Loss of anonymity may occur due to the nature of this research in that only those with head injuries will be re-tested on the NeuroTracker. All attempts will be made to ensure your data remain anonymous.

#### **Confidentiality**

Your confidentiality and the confidentiality of the data will be protected by storing all data in a password protected computer program (i.e., NeuroTracker system) and excel file. All paperwork will be stored in a locked filing cabinet. De-identified NeuroTracker data will also be shared with and stored by Cognisens Inc. Cognisens Inc. may use this de-identified data for future analyses. Online surveys will be administered using Limesurvey, which encrypts your data. You will also be provided with a randomly generated number so that your data are not stored with your personal information electronically.

#### **Dissemination of Results**

It is anticipated that the results of this study will be shared with others in the following ways:

- 1) Directly to participants and/or the parents of the participants via Summary Reports;
- 2) Published articles;
- 3) Presentations at scholarly meetings;
- 4) Company promotions (Cognisens Inc.).

#### **Disposal of Data**

Data from this study will not be disposed of but will be stored in a password protected database by Cognisens Inc.

PARTICIPANT NUMBER: \_\_\_\_\_

**Future Use of Data** PLEASE SELECT 1 OF THE STATEMENTS BELOW:

I consent to the use of my data in future research: \_\_\_\_\_ (Participant to provide initials)

I **do not** consent to the use of my data in future research: \_\_\_\_\_ (Participant to provide initials)

I consent to be contacted in the event my data is requested for future research: \_\_\_\_\_ (Participant to provide initials)

**Contacts**

Individuals that may be contacted regarding this study include:

Dr. Brian Christie, Principal Investigator      Phone: (250) 472-4244  
Email: [brain64@uvic.ca](mailto:brain64@uvic.ca)Project coordinator      Phone: (250) 472-5997 or (250)634-4471 (lab cell)  
Email: [brainlab@uvic.ca](mailto:brainlab@uvic.ca)In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or [ethics@uvic.ca](mailto:ethics@uvic.ca)).

Your signature below indicates that you understand the above conditions of participation in this study, that you have had the opportunity to have your questions answered by the researchers, and that you give your consent for your child to participate in this research project.

_____	_____	_____
<i>Name of Participant</i>	<i>Signature of Participant</i>	<i>Date</i>
_____	_____	_____
<i>Name of Parent/Guardian</i>	<i>Signature of Parent/Guardian</i>	<i>Date</i>

## Appendix B – Participant Assent

*Participant Assent Form***ASSENT TO BE IN A RESEARCH STUDY ABOUT  
CONCUSSIONS**

The following script is to be read to all children 5-12 years old.

**Why are we meeting with you?**

We want to tell you about something we are doing called a research study. A research study is when doctors collect a lot of information to learn more about something. We are doing a study to learn more about children with head injuries. After we tell you about it, we will ask if you'd like to be in this study or not.

**Why are we doing this study?**

We want to find out how well our computer game helps us learn about what happens when children hurt their heads playing sports, so we are getting information from lots of boys and girls like you. In the whole study, there will be over 1000 children and adults.

**What will happen to you if you are in this study?**

1. You will be asked to play our computer game for about 20-30 minutes. This is the same computer game that players in the National Hockey League use to help them train.
2. If you ever hurt your head you'll be able to come back and play the game again.
3. If you have already hurt your head, you can still come in and play the game.

You will also complete a couple quick tests of your thinking and balance and reaction time,

The purpose of playing this game and testing is we think it can help us figure out when it will be safe for you to play sports and other activities again. You'll be able to play the game as many times as it takes to help you do as well on it as before you got hurt, and when you feel ready, you can go see your doctor again and see if he also thinks you're ready return to sports and other activities. We want you to have a great time play sports and doing your usual activities.

**Do you have any questions?**

You can ask questions any time. You can ask now. You can ask later. You can talk to me or you can talk to someone else and have them talk to me.

**Do you have to be in this study?**

No, you don't. No one will be mad at you if you don't want to do this. If you don't want to be in this study, just tell us. Or if you do want to be in the study, tell us that. And, remember, you can say yes now and change your mind later. It's all up to you.

**SIGNATURE OF PERSON CONDUCTING ASSENT DISCUSSION**

I have explained the study to \_\_\_\_\_ (*print name of child here*) in language he/she can understand, and the child has agreed to be in the study.

\_\_\_\_\_  
Signature of Person Conducting Assent Discussion

\_\_\_\_\_  
Date

\_\_\_\_\_  
Name of Person Conducting Assent Discussion (*print*)

## Appendix C – Medical History Intake

Group		Participant Number	
DOB (yyyy/mm/dd)		Gender	
Date (yyyy/mm/dd)		Baseline or Post-injury	

## MOT AND RELATED TESTING – INTAKE FORM

CONTACT INFORMATION			
First Name		Last Name	
Phone (home)		Phone (cell)	
Email			

EMERGENCY CONTACT INFORMATION			
First Name		Last Name	
Phone (home)		Phone (cell)	
Email			
Relationship to You			

GENERAL INFORMATION			
Height (ft)		Weight (lbs)	
Age		DOB (yyyy/mm/dd)	
Gender		Highest Education Level	
What hand do you write with?			
What hand do you shoot a hockey puck with?			
What hand do you use to throw a ball?			

EXTRA CURRICULARS			
List any instruments you play		For how many years?	
Do you play video games?		For how many hrs/wk?	

CURRENT SPORT PARTICIPATION			
SPORT	POSITION	LEVEL	YEARS

PREVIOUS SPORT PARTICIPATION			
SPORT	POSITION	CURRENT LEVEL	YEARS TOTAL




Appendix D – Sport Concussion Assessment Tool – 3<sup>rd</sup> EditionDownloaded from [bjsm.bmj.com](http://bjsm.bmj.com) on September 5, 2013 - Published by [group.bmj.com](http://group.bmj.com)

# SCAT3™

## Sport Concussion Assessment Tool – 3rd Edition

For use by medical professionals only



Name

Date/Time of Injury:  
Date of Assessment:

Examiner:

**What is the SCAT3?**

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<sup>1</sup>. 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<sup>2</sup>. 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?	<input type="checkbox"/> Y	<input type="checkbox"/> N
*If so, how long? _____		
Balance or motor incoordination (stumbles, slow/laboured movements, etc)?	<input type="checkbox"/> Y	<input type="checkbox"/> N
Disorientation or confusion (inability to respond appropriately to questions)?	<input type="checkbox"/> Y	<input type="checkbox"/> N
Loss of memory:	<input type="checkbox"/> Y	<input type="checkbox"/> N
*If so, how long? _____		
*Before or after the injury? _____		
Blank or vacant look:	<input type="checkbox"/> Y	<input type="checkbox"/> N
Visible facial injury in combination with any of the above:	<input type="checkbox"/> Y	<input type="checkbox"/> N

**1 Glasgow coma scale (GCS)**

<b>Best eye response (E)</b>	
No eye opening	1
Eye opening in response to pain	2
Eye opening to speech	3
Eyes opening spontaneously	4
<b>Best verbal response (V)</b>	
No verbal response	1
Incomprehensible sounds	2
Inappropriate words	3
Confused	4
Oriented	5
<b>Best motor response (M)</b>	
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
<b>Glasgow Coma score (E + V + M)</b>	<b>of 15</b>

GCS should be recorded for all athletes in case of subsequent deterioration.

**2 Maddocks Score<sup>3</sup>**

*"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
<b>Maddocks score</b>	<b>of 5</b>	

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.**

## 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

SCAT3 to be done in resting state. Best done 10 or more minutes post exercise.

## SYMPTOM EVALUATION

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### How do you feel?

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

	none	mild	moderate	severe			
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6

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

self rated  self rated and clinician monitored  
 clinician interview  self rated with parent input

**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:

no different  very different  unsure  N/A

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

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### Cognitive assessment

#### Standardized Assessment of Concussion (SAC)<sup>4</sup>

**Orientation** (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1

**Orientation score** \_\_\_\_\_ of 5

#### Immediate memory

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

**Immediate memory score total** \_\_\_\_\_ of 15

#### Concentration: Digits Backward

List	Trial 1	Alternative digit list			
4-9-3	0	1	6-2-9	5-2-6	4-1-5
3-8-1-4	0	1	3-2-7-9	1-7-9-5	4-9-6-8
6-2-9-7-1	0	1	1-5-2-8-6	3-8-5-2-7	6-1-8-4-3
7-1-8-4-6-2	0	1	5-3-9-1-4-8	8-3-1-9-6-4	7-2-4-8-5-6
<b>Total of 4</b>					

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

Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan  0  1

**Concentration score** \_\_\_\_\_ of 5

5

### Neck Examination:

Range of motion \_\_\_\_\_ Tenderness \_\_\_\_\_ Upper and lower limb sensation & strength \_\_\_\_\_

**Findings:** \_\_\_\_\_

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### Balance examination

Do one or both of the following tests.

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

#### Modified Balance Error Scoring System (BESS) testing<sup>4</sup>

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 gait<sup>4</sup>

Time (best of 4 trials): \_\_\_\_\_ seconds

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### Coordination examination

#### Upper limb coordination

Which arm was tested:  Left  Right

**Coordination score** \_\_\_\_\_ of 1

8

### SAC Delayed Recall<sup>4</sup>

**Delayed recall score** \_\_\_\_\_ of 5

## INSTRUCTIONS

Words in *italics* throughout the ChildSCAT3 are the instructions given to the child by the tester.

### Sideline Assessment – child-Maddocks Score

To be completed on the sideline/in the playground, immediately following concussion. There is no requirement to repeat these questions at follow-up.

### Symptom Scale\*

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.

#### On the day of injury

- the child is to complete the Child Report, according to how he/she feels now.

#### On all subsequent days

- the child is to complete the Child Report, according to how he/she feels today, **and**  
- the parent/carer is to complete the Parent Report according to how the child has been over the previous 24 hours.

### Standardized Assessment of Concussion – Child Version (SAC-C)\*

#### Orientation

Ask each question on the score sheet. A correct answer for **each question scores 1 point**. If the child does not understand the question, gives an incorrect answer, or no answer, then the score for that question is 0 points.

#### 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 child 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, you would say 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.

##### Days in Reverse Order:

*"Now tell me the days of the week in reverse order. Start with Sunday and go backward. So you'll say Sunday, Saturday... Go ahead"*

**1 pt. for entire sequence correct**

##### Delayed recall

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

*"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."*

Circle each word correctly recalled. **Total score equals number of words recalled.**

### Balance examination

These instructions are to be read by the person administering the ChildSCAT3, and each balance task should be demonstrated to the child. The child should then be asked to copy what the examiner demonstrated.

#### Modified Balance Error Scoring System (BESS) testing\*

This balance testing is based on a modified version of the Balance Error Scoring System (BESS)<sup>8</sup>. 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 two different parts."*

##### (a) Double leg stance:

The first stance is standing with the feet together with hands on hips and with eyes closed. The child should try to maintain stability in that position for 20 seconds. You should inform the child that you will be counting the number of times the child moves out of this position. You should start timing when the child is set and the eyes are closed.

##### (b) Tandem stance:

Instruct the child to stand heel-to-toe with the non-dominant foot in the back. Weight should be evenly distributed across both feet. Again, the child should try to maintain stability for 20 seconds with hands on hips and eyes closed. You should inform the child that you will be counting the number of times the child moves out of this position. If the child stumbles out of this position, instruct him/her to open the eyes and return to the start position and continue balancing. You should start timing when the child is set and the eyes are closed.

#### Balance testing – types of errors - Parts (a) and (b)

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 child. The examiner will begin counting errors only after the child has assumed the proper start position. **The modified BESS is calculated by adding one error point for each error during the two 20-second tests. The maximum total number of errors for any single condition is 10.** If a child commits multiple errors simultaneously, only one error is recorded but the child should quickly return to the testing position, and counting should resume once subject is set. Children 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 2 stances can be performed on a surface of medium density foam (e.g., approximately 50cm x40cm x6cm).

#### Tandem Gait<sup>9</sup>

Use a clock (with a second hand) or stopwatch to measure the time taken to complete this task. Instruction for the examiner – **Demonstrate the following to the child:**

*The child is 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 30mm 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. Children 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.*

Explain to the child that you will time how long it takes them to walk to the end of the line and back.

### Coordination examination

#### Upper limb coordination

Finger-to-nose (FTN) task:

The tester should demonstrate it to the child.

*"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). 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 as quickly and as accurately as possible."*

**Scoring: 5 correct repetitions in < 4 seconds = 1**

**Note for testers:** Children 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 BJSM 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.
2. McCrory P et al., Consensus Statement on Concussion in Sport – the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. British Journal of Sports Medicine 2009; 43: 176-89.
3. Maddocks, DL; Dicker, GD; Saling, MM. The assessment of orientation following concussion in athletes. Clinical Journal of Sport Medicine. 1995; 5(1): 32-3.
4. McCrea M. Standardized mental status testing of acute concussion. Clinical Journal of Sport Medicine. 2001; 11: 176-181.
5. Guskiewicz KM. Assessment of postural stability following sport-related concussion. Current Sports Medicine Reports. 2003; 2: 24-30.
6. Schneiders, A.G., Sullivan, S.J., Gray, A., Hammond-Tooke, G.&McCrory, P. Normative values for 16-37 year old subjects for three clinical measures of motor performance used in the assessment of sports concussions. Journal of Science and Medicine in Sport. 2010; 13(2): 196-201.
7. Schneiders, A.G., Sullivan, S.J., Kvamstrom, J.K., Olsson, M., Yden, T.&Marshall, S.W. The effect of footwear and sports-surface on dynamic neurological screening in sport-related concussion. Journal of Science and Medicine in Sport. 2010; 13(4): 382-386
8. Ayr, L.K., Yeates, K.O., Taylor, H.G., &Brown, M. Dimensions of post-concussive symptoms in children with mild traumatic brain injuries. Journal of the International Neuropsychological Society. 2009; 15:19-30.

## Appendix E – Child - Sport Concussion Assessment Tool 3

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# Child-SCAT3™



## Sport Concussion Assessment Tool for children ages 5 to 12 years

For use by medical professionals only

**What is childSCAT3?**

The ChildSCAT3 is a standardized tool for evaluating injured children for concussion and can be used in children aged from 5 to 12 years. It supersedes the original SCAT and the SCAT2 published in 2005 and 2009, respectively. For older persons, ages 13 years and over, please use the SCAT3. The ChildSCAT3 is designed for use by medical professionals. If you are not qualified, please use the Sport Concussion Recognition Tool. Preseason baseline testing with the ChildSCAT3 can be helpful for interpreting post-injury test scores.

Specific instructions for use of the ChildSCAT3 are provided on page 3. If you are not familiar with the ChildSCAT3, 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 and any reproduction in a digital form require approval by the Concussion in Sport Group.

**NOTE:** The diagnosis of a concussion is a clinical judgment, ideally made by a medical professional. The ChildSCAT3 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 ChildSCAT3 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 (like those 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 severe brain injury. If the concussed child displays any of the following, then do not proceed with the ChildSCAT3; instead activate 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
- Persistent vomiting
- Evidence of skull fracture
- Post traumatic seizures
- Coagulopathy
- History of Neurosurgery (eg Shunt)
- Multiple Injuries

1

**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

GCS should be recorded for all athletes in case of subsequent deterioration.

**Potential signs of concussion?**

If any of the following signs are observed after a direct or indirect blow to the head, the child 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?	<input type="checkbox"/> Y <input type="checkbox"/> N
"If so, how long?" _____	
Balance or motor incoordination (stumbles, slow/laboured movements, etc.)?	<input type="checkbox"/> Y <input type="checkbox"/> N
Disorientation or confusion (inability to respond appropriately to questions)?	<input type="checkbox"/> Y <input type="checkbox"/> N
Loss of memory:	<input type="checkbox"/> Y <input type="checkbox"/> N
"If so, how long?" _____	
"Before or after the injury?" _____	
Blank or vacant look:	<input type="checkbox"/> Y <input type="checkbox"/> N
Visible facial injury in combination with any of the above:	<input type="checkbox"/> Y <input type="checkbox"/> N

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**Sideline Assessment – child-Maddocks Score<sup>3</sup>**

"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)

Where are we at now?	0	1
Is it before or after lunch?	0	1
What did you have last lesson/class?	0	1
What is your teacher's name?	0	1
<b>child-Maddocks score</b>		<b>of 4</b>

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

**Any child with a suspected concussion should be REMOVED FROM PLAY, medically assessed and monitored for deterioration (i.e., should not be left alone). No child diagnosed with concussion should be returned to sports participation on the day of injury.**

**BACKGROUND**

Name: \_\_\_\_\_ Date/Time of Injury: \_\_\_\_\_  
 Examiner: \_\_\_\_\_ Date of Assessment: \_\_\_\_\_  
 Sport/team/school: \_\_\_\_\_  
 Age: \_\_\_\_\_ Gender:  M  F  
 Current school year/grade: \_\_\_\_\_  
 Dominant hand:  right  left  neither  
 Mechanism of Injury ("tell me what happened"): \_\_\_\_\_

**For Parent/carer to complete:**

How many concussions has the child had in the past? \_\_\_\_\_  
 When was the most recent concussion? \_\_\_\_\_  
 How long was the recovery from the most recent concussion? \_\_\_\_\_  
 Has the child ever been hospitalized or had medical imaging done (CT or MRI) for a head injury?  Y  N  
 Has the child ever been diagnosed with headaches or migraines?  Y  N  
 Does the child have a learning disability, dyslexia, ADD/ADHD, seizure disorder?  Y  N  
 Has the child ever been diagnosed with depression, anxiety or other psychiatric disorder?  Y  N  
 Has anyone in the family ever been diagnosed with any of these problems?  Y  N  
 Is the child on any medications? If yes, please list:  Y  N

## SYMPTOM EVALUATION

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## Child report

Name:	never	rarely	sometimes	often
I have trouble paying attention	0	1	2	3
I get distracted easily	0	1	2	3
I have a hard time concentrating	0	1	2	3
I have problems remembering what people tell me	0	1	2	3
I have problems following directions	0	1	2	3
I daydream too much	0	1	2	3
I get confused	0	1	2	3
I forget things	0	1	2	3
I have problems finishing things	0	1	2	3
I have trouble figuring things out	0	1	2	3
It's hard for me to learn new things	0	1	2	3
I have headaches	0	1	2	3
I feel dizzy	0	1	2	3
I feel like the room is spinning	0	1	2	3
I feel like I'm going to faint	0	1	2	3
Things are blurry when I look at them	0	1	2	3
I see double	0	1	2	3
I feel sick to my stomach	0	1	2	3
I get tired a lot	0	1	2	3
I get tired easily	0	1	2	3

Total number of symptoms (Maximum possible 20)

Symptom severity score (Maximum possible 20x3=60)

 self rated     clinician interview     self rated and clinician monitored

4

## Parent report

The child	never	rarely	sometimes	often
has trouble sustaining attention	0	1	2	3
is easily distracted	0	1	2	3
has difficulty concentrating	0	1	2	3
has problems remembering what he/she is told	0	1	2	3
has difficulty following directions	0	1	2	3
tends to daydream	0	1	2	3
gets confused	0	1	2	3
is forgetful	0	1	2	3
has difficulty completing tasks	0	1	2	3
has poor problem solving skills	0	1	2	3
has problems learning	0	1	2	3
has headaches	0	1	2	3
feels dizzy	0	1	2	3
has a feeling that the room is spinning	0	1	2	3
feels faint	0	1	2	3
has blurred vision	0	1	2	3
has double vision	0	1	2	3
experiences nausea	0	1	2	3
gets tired a lot	0	1	2	3
gets tired easily	0	1	2	3

Total number of symptoms (Maximum possible 20)

Symptom severity score (Maximum possible 20x3=60)

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

 parent self rated     clinician interview     parent self rated and clinician monitored

 Overall rating for parent/teacher/coach/carer to answer.  
 How different is the child acting compared to his/her usual self?

 Please circle one response:  
 no different     very different     unsure     N/A

Name of person completing Parent-report: \_\_\_\_\_

Relationship to child of person completing Parent-report: \_\_\_\_\_

Scoring on the ChildSCAT3 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.

## COGNITIVE &amp; PHYSICAL EVALUATION

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## Cognitive assessment

Standardized Assessment of Concussion - Child Version (SAC-C)<sup>†</sup>

## Orientation (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1

Orientation score **of 4**

## Immediate memory

List	Trial 1	Trial 2	Trial 3	Alternative word list					
elbow	0	1	0	1	0	1	candle	baby	finger
apple	0	1	0	1	0	1	paper	monkey	penny
carpet	0	1	0	1	0	1	sugar	perfume	blanket
saddle	0	1	0	1	0	1	sandwich	sunset	lemon
bubble	0	1	0	1	0	1	wagon	iron	insect
Total									

Immediate memory score total **of 15**

## Concentration: Digits Backward

List	Trial 1	Alternative digit list			
6-2	0	1	5-2	4-1	4-9
4-9-3	0	1	6-2-9	5-2-6	4-1-5
3-8-1-4	0	1	3-2-7-9	1-7-9-5	4-9-6-8
6-2-9-7-1	0	1	1-5-2-8-6	3-8-5-2-7	6-1-8-4-3
7-1-8-4-6-2	0	1	5-3-9-1-4-8	8-3-1-9-6-4	7-2-4-8-5-6
Total of 5					

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

Sunday-Saturday-Friday-Thursday-Wednesday-Tuesday-Monday	0	1
--	---	---

Concentration score **of 6**

6

## Neck Examination:

Range of motion    Tenderness    Upper and lower limb sensation &amp; strength

Findings: \_\_\_\_\_

7

## Balance examination

Do one or both of the following tests.

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

Modified Balance Error Scoring System (BESS) testing<sup>†</sup>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

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

Tandem gait<sup>†</sup>Time taken to complete one of 4 trials: \_\_\_\_\_ secondsIf child attempted, but unable to complete tandem gait, mark here 

8

## Coordination examination

## Upper limb coordination

Which arm was tested:  Left  RightCoordination score **of 1**

9

SAC Delayed Recall<sup>†</sup>Delayed recall score **of 5**

Since signs and symptoms may evolve over time, it is important to consider repeat evaluation in the acute assessment of concussion.

## INSTRUCTIONS

Words in *italics* throughout the ChildSCAT3 are the instructions given to the child by the tester.

### Sideline Assessment – child-Maddocks Score

To be completed on the sideline/in the playground, immediately following concussion. There is no requirement to repeat these questions at follow-up.

### Symptom Scale\*

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.

#### On the day of injury

- the child is to complete the Child Report, according to how he/she feels now.

#### On all subsequent days

- the child is to complete the Child Report, according to how he/she feels today, **and**  
- the parent/carer is to complete the Parent Report according to how the child has been over the previous 24 hours.

### Standardized Assessment of Concussion – Child Version (SAC-C)\*

#### Orientation

Ask each question on the score sheet. A correct answer for each question scores 1 point. If the child does not understand the question, gives an incorrect answer, or no answer, then the score for that question is 0 points.

#### 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 child 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, you would say 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.

##### Days in Reverse Order:

*"Now tell me the days of the week in reverse order. Start with Sunday and go backward. So you'll say Sunday, Saturday ... Go ahead"*

**1 pt. for entire sequence correct**

##### Delayed recall

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

*"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."*

Circle each word correctly recalled. **Total score equals number of words recalled.**

### Balance examination

These instructions are to be read by the person administering the ChildSCAT3, and each balance task should be demonstrated to the child. The child should then be asked to copy what the examiner demonstrated.

#### Modified Balance Error Scoring System (BESS) testing\*

This balance testing is based on a modified version of the Balance Error Scoring System (BESS)<sup>8</sup>. 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 two different parts."*

##### (a) Double leg stance:

*The first stance is standing with the feet together with hands on hips and with eyes closed. The child should try to maintain stability in that position for 20 seconds. You should inform the child that you will be counting the number of times the child moves out of this position. You should start timing when the child is set and the eyes are closed.*

##### (b) Tandem stance:

*Instruct the child to stand heel-to-toe with the non-dominant foot in the back. Weight should be evenly distributed across both feet. Again, the child should try to maintain stability for 20 seconds with hands on hips and eyes closed. You should inform the child that you will be counting the number of times the child moves out of this position. If the child stumbles out of this position, instruct him/her to open the eyes and return to the start position and continue balancing. You should start timing when the child is set and the eyes are closed.*

#### Balance testing – types of errors - Parts (a) and (b)

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 child. The examiner will begin counting errors only after the child has assumed the proper start position. **The modified BESS is calculated by adding one error point for each error during the two 20-second tests. The maximum total number of errors for any single condition is 10.** If a child commits multiple errors simultaneously, only one error is recorded but the child should quickly return to the testing position, and counting should resume once subject is set. Children 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 2 stances can be performed on a surface of medium density foam (e.g., approximately 50cm x 40cm x 6cm).

#### Tandem Gait\*

Use a clock (with a second hand) or stopwatch to measure the time taken to complete this test. **Instruction for the examiner – Demonstrate the following to the child.**

*The child is 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. Children 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.*

Explain to the child that you will time how long it takes them to walk to the end of the line and back.

### Coordination examination

#### Upper limb coordination

##### Finger-to-nose (FTN) task:

The tester should demonstrate it to the child.

*"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). 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 as quickly and as accurately as possible."*

**Scoring: 5 correct repetitions in < 4 seconds = 1**

**Note for testers:** Children 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 BISM 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.
2. McCrory P et al., Consensus Statement on Concussion in Sport – the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. British Journal of Sports Medicine 2009; 43: 176–89.
3. Maddocks, DL; Dicker, GD; Saling, MM. The assessment of orientation following concussion in athletes. Clinical Journal of Sport Medicine. 1995; 5(1): 32–3.
4. McCrea M. Standardized mental status testing of acute concussion. Clinical Journal of Sport Medicine. 2001; 11: 176–181.
5. Guskiewicz KM. Assessment of postural stability following sport-related concussion. Current Sports Medicine Reports. 2003; 2: 24–30.
6. Schneiders, A.G., Sullivan, S.J., Gray, A., Hammond-Tookey, G. & McCrory, P. Normative values for 16–37 year old subjects for three clinical measures of motor performance used in the assessment of sports concussions. Journal of Science and Medicine in Sport. 2010; 13(2): 196–201.
7. Schneiders, A.G., Sullivan, S.J., Kwamstrom, J.K., Olsson, M., Yden, T. & Marshall, S.W. The effect of footwear and sports-surface on dynamic neurological screening in sport-related concussion. Journal of Science and Medicine in Sport. 2010; 13(4): 382–386
8. Ayr, L.K., Yeates, K.O., Taylor, H.G., & Brown, M. Dimensions of post-concussive symptoms in children with mild traumatic brain injuries. Journal of the International Neuropsychological Society. 2009; 15:19–30.

## Appendix F – King-Devick Test



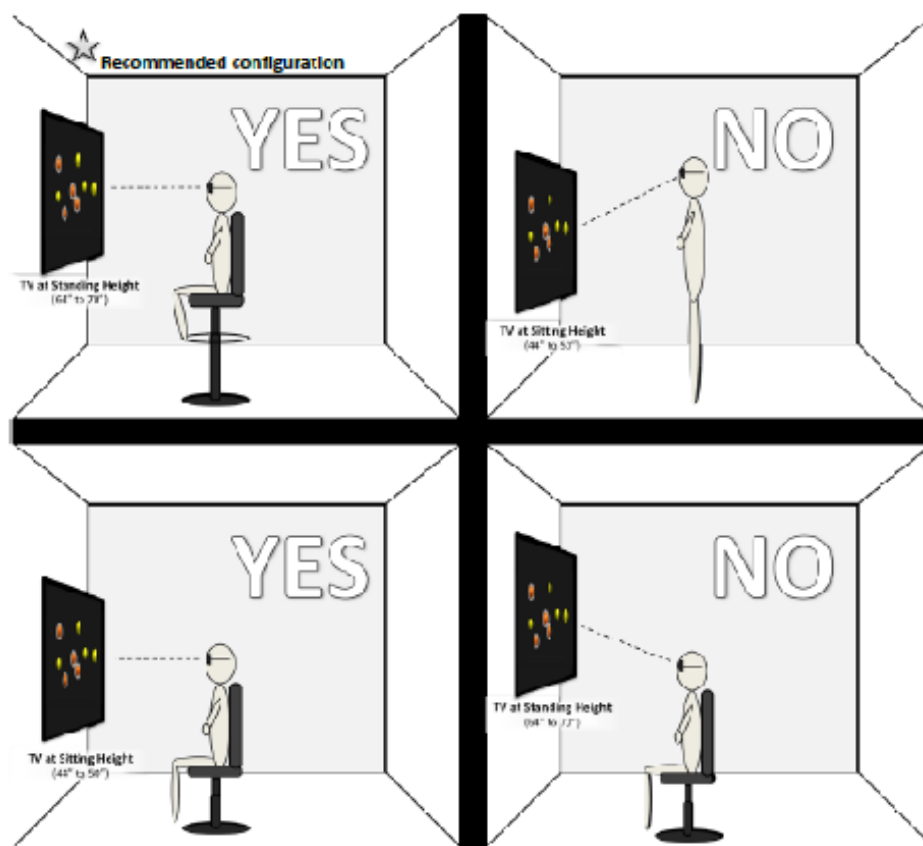
University  
of Victoria

## King Devick Test Form



Participant Number			
<p>Test Card 1</p> <p>2-5-8-0-7 3-7-9-4-6 5-3-1-6-4 7-9-7-3-5 1-5-4-9-2 6-5-5-7-3 3-1-8-6-4 5-3-7-5-2</p> <p>Time:</p>	<p>Test Card 2</p> <p>3-7-5-9-0 2-5-7-4-6 1-4-7-6-3 7-9-3-9-0 4-5-2-1-7 5-3-7-4-8 7-4-6-5-2 9-0-2-3-6</p> <p>Time:</p>	<p>Test Card 3</p> <p>5-4-1-8-0 4-6-3-5-9 7-5-4-2-7 3-2-6-9-4 1-4-5-1-3 9-3-4-8-5 5-1-6-3-1 4-3-5-2-7</p> <p>Time:</p>	<p>Date: _____</p> <p>Total Time: _____</p> <p>Total Errors _____</p> <p>Test Cards: _____</p> <p>Tester Initials: _____</p>
<p>Test Card 1</p> <p>2-5-8-0-7 3-7-9-4-6 5-3-1-6-4 7-9-7-3-5 1-5-4-9-2 6-5-5-7-3 3-1-8-6-4 5-3-7-5-2</p> <p>Time:</p>	<p>Test Card 2</p> <p>3-7-5-9-0 2-5-7-4-6 1-4-7-6-3 7-9-3-9-0 4-5-2-1-7 5-3-7-4-8 7-4-6-5-2 9-0-2-3-6</p> <p>Time:</p>	<p>Test Card 3</p> <p>5-4-1-8-0 4-6-3-5-9 7-5-4-2-7 3-2-6-9-4 1-4-5-1-3 9-3-4-8-5 5-1-6-3-1 4-3-5-2-7</p> <p>Time:</p>	<p>Date: _____</p> <p>Total Time: _____</p> <p>Total Errors _____</p> <p>Test Cards: _____</p> <p>Tester Initials: _____</p>
<p>Test Card 1</p> <p>2-5-8-0-7 3-7-9-4-6 5-3-1-6-4 7-9-7-3-5 1-5-4-9-2 6-5-5-7-3 3-1-8-6-4 5-3-7-5-2</p> <p>Time:</p>	<p>Test Card 2</p> <p>3-7-5-9-0 2-5-7-4-6 1-4-7-6-3 7-9-3-9-0 4-5-2-1-7 5-3-7-4-8 7-4-6-5-2 9-0-2-3-6</p> <p>Time:</p>	<p>Test Card 3</p> <p>5-4-1-8-0 4-6-3-5-9 7-5-4-2-7 3-2-6-9-4 1-4-5-1-3 9-3-4-8-5 5-1-6-3-1 4-3-5-2-7</p> <p>Time:</p>	<p>Date: _____</p> <p>Total Time: _____</p> <p>Total Errors _____</p> <p>Test Cards: _____</p> <p>Tester Initials: _____</p>

## Appendix G – 3D-MOT



#### TV Height and Chair Height

When setting up a NeuroTracker Pro system, it is important to position the center of the TV at the same height as the user's eyes. Failure to do so can result in visual distortions which will negatively impact training results.

If all training sessions will be done sitting down, then the center of the TV should be 44" to 50" off the ground, unless the chair is an unusual height.

If users will be training standing up, then the center of the TV should be 64" to 70" off the ground.

It is strongly recommended to use a chair with a seat height adjustment mechanism, to accommodate users of different heights.

TV Size	Distance from TV
65 inch	5ft 8 in (173cm)
60 inch	5ft 3 in (160cm)
55 inch	4ft 10 in (147cm)
50 inch	4ft 5 in (133cm)
User Position	TV Height (Center)
Standing / High chair	5ft 4 in (163 cm) to 5ft 10 in (178 cm)
Sitting / Low chair	3ft 8 in (112 cm) to 4ft 2 in (127 cm)

**Standardized Protocol for the NeuroTracker™ as published by Cognisens**

1. On the screen, you will see eight yellow balls in 3D.
  2. Once we begin, four of the balls will turn orange.
  3. Memorize which balls have turned orange.
  4. The orange balls will turn back to yellow and all eight balls will begin to move around the screen.
  5. Your goal is to track the four balls that had previously turned orange.
  6. Once the balls stop, a number will show up next to each ball.
  7. Using the numbers, identify which balls were previously orange.
  8. If you correctly identified the four orange balls, the speed of the moving balls will speed up on the next trial.
  9. If you incorrectly identify the four orange balls, the speed of the moving balls will slow down on the next trial.
  10. Feedback on whether you correctly identified the orange balls will be given on the screen.
  11. You will complete 20 trials per session and each session will take about eight minutes.
  12. After your first session is complete, you will have a short break of about five minutes.
  13. You will complete three sessions of 20 trials today.
- The participant will be given 3D glasses to wear and will sit in a chair facing a large screen where the computer program will be displayed.
  - The computer program will begin once the participant acknowledges their readiness.
  - No feedback on performance will be given to the participant at any time.

## Appendix H – Ethics Certificate

*Board of Record*  
University of Victoria

**Certificate of Renewed Ethical Approval for  
Harmonized Minimal Risk Health Study**

Human Research Ethics Board (HREB)  
Administrative Services Building  
Room B202  
PO Box 1700 STN CSC  
Victoria, BC V8V 2Y2

Also reviewed and approved by:  
Island Health




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<b>Principal Investigators:</b> <b>Brian Christie</b>	<b>Primary Appointment:</b> <b>University of Victoria</b>	<b>Board of Record Approval Reference #:</b> <b>BC12-271</b>
<b>Study Title:</b> Vancouver Island Concussion Project: Study2—Neurotracker Study		
<b>Study Renewed:</b> 4 AUG 2016	<b>Expiry Date:</b> 22 JUL 2017	
<b>Research Team Members:</b>	Francesca Bell-Peters (Study Coordinator) Research Assistants (UVic): Shae Wale, Kim Oslund, Erika Shaw, Hilary Cullen, Allison Rodway, Samantha Kennedy, Julie Irwin, Stephani Fischer, Josh Palmer, Sean Harrigan, Carmela De Gracia, Erin Williams, Taylor Matson, Sara Martin, Taya Sparks, Caroline Spaner, Rachelle Smith, Teresa Anania, Damon Taylor, Andrea Jeffs, Chantelle Elvadahl, Emma Rigsby, Bree Neele, Hanna Lindores, Hailee Daymon.	

**Sponsoring Agencies:** CIHR

Documents included

In this approval:

Document Name	Approved version date
Human Research Ethics Request for Annual Renewal	Aug 4, 2016

This ethics approval applies to research ethics issues only and does not include provision for any administrative approvals required from individual institutions before research activities can commence.

The Board of Record (as noted above) has reviewed and approved this study in accordance with the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2, 2014).

The "Board of Record" is the Research Ethics board designated on behalf of the participating REBs involved in a harmonized study to facilitate the ethics review and approval process. In the event that there are any changes or amendments to this approved protocol, please notify the Board of Record.

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**Board of Record Research Ethics Board Representative**

**Name:** Dr. Rachael Scarth

**Title:** Associate VP Research Operations

**Signature:**

**Date:** Aug 4, 2016