

VESTIBULAR AND OCULAR MOTOR BASELINE CONCUSSION ASSESSMENT IN
YOUTH ATHLETES

By

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PUBLIC ABSTRACT

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Purpose: The purpose of this study was to investigate sex differences on the Vestibular/Ocular Motor Screening (VOMS) and King-Devick (KD) tests among youth athletes. A secondary purpose of this study was to examine the relationship between KD test performance and ocular performance on the VOMS assessment in youth athletes. **Methods:** A total of 468 youth athletes from mid-Michigan youth sport organizations between the ages of 8 and 14 volunteered to participate in the study. All athletes completed the VOMS and KD tests at the beginning of their sport season. **Results:** Youth female athletes had significantly better performance on the KD test than male youth athletes, but there were no sex differences recorded on the VOMS test. In addition, there was a poor relationship between the KD and VOMS test. Additional information, including a history of concussion and learning disability did not demonstrate any differences on VOMS and KD test performance. **Conclusions:** Sex differences occurred on the KD, with youth female athletes performing better than male youth athletes; however no sex differences were noted on the VOMS test.

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I dedicate this dissertation to my family, from whom this was all possible. You all have stood by me for my entire life and provided me with every opportunity possible. Without you I wouldn't be where I am today. I am extremely blessed and love you all so very much!

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Go Green!

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CHAPTER 1

INTRODUCTION

1.1 Overview of the Problem

Concussions in sport remain a growing concern for athletes, parents, coaches, and health care professionals. An epidemiological study estimated that 1.6 to 3.8 million sport-related concussions occur annually in the United States (Langlois, Rutland-Brown, & Wald, 2006). Athletic trainers, physicians, and health care professionals all rely on assessment strategies and tools to help recognize, diagnose, and manage concussions. The National Athletic Trainers' Association (NATA) position statement emphasizes the implementation and use of baseline concussion testing, to assist with sport-related concussion assessment and management (Broglio, Cantu, Gioia, Guskiewicz, Kutcher, Palm, & Valovich McLeod, 2014). Therefore, it is recommended that baseline assessment contain objective evaluations across many areas of brain function, including self-reported symptoms, neurocognitive assessment, motor control, and mental status testing.

A concussion typically presents with a myriad of physical, emotional, cognitive, somatic, and sleep related symptoms and impairments (Giza et al., 2013; McCrory et al., 2013). Approximately 80-90% of these impairments from concussion typically resolve within 7-10 days (McCrory et al., 2013, McCrea et al., 2003), but some athletes remain symptomatic or impaired for weeks or months after concussion (Leddy et al., 2012, Willer & Leddy, 2006; Binder, Rohling, & Larrabee, 1997). More recently it has been reported that vestibular impairments are common after a concussion and can delay recovery (Hoffer et al., 2004; Corwin et al, 2015; Zhou & Brodsky, 2015). In addition, it has been reported that ocular impairments and symptoms are also common after concussion (Heitger, Anderson, & Jones, 2008; Kontos et al., 2012; Cap-

Aponte, Urosevich, Temme, Tarbett, & Sanghera, 2012). In fact, it is estimated that 65-90% of individuals who have sustained a form of traumatic brain injury have a certain degree of oculomotor dysfunction (Ciuffreda, Kapoor, Rutner, Suchoff, & Han, 2007). Kontos et al. (2012) also reported that 30% of vision difficulties are reported in concussed individuals. Vision and oculomotor-related symptoms following sports-related concussion may include headache, dizziness, nausea, diplopia, blurred vision, and difficulty tracking a moving target (Ciuffreda, Kapoor, Rutner, Suchoff, Han, & Craig, 2007); however, this can be complicated due to the fact the identification of symptoms is dependent upon the athlete's subjective reporting. As a result, many concussions go unreported in order to remain in the game or feel pressured from parent, coaches, teammates, and fans to continue to play (Kroshus, Garnett, Hawrilenko, Baugh, & Calzo, 2015).

One of the more recent developments in concussion research is the assessment of the vestibular and ocular systems of the body. Recent research has emphasized the need for vestibular system assessment, as 40%-50% of athletes with a sport-related concussion, report balance dysfunction and dizziness, which are underlying impairments to the vestibular system (Mucha et al., 2014). Previous research has been conducted on vestibular rehabilitation in sport-related concussion recovery (Leddy, Sandhu, Sodhu, Baker, & Willer, 2012; Alsalaheen, Mucha, Morris, Whitney, Furman, Camiolo-Reddy, Collins, Lovell, & Sparto, 2010; Gottshall & Hoffer, 2010), but very little research has investigated assessment, beyond balance and gait. A new clinical model for the treatment of sport-related concussion has suggested that vestibular and ocular motor symptoms and impairment may constitute different clinical sub-types (Collins et al., 2014). Proper recognition and diagnosis of these clinical trajectories (vestibular, ocular, mood and anxiety, migraine headaches, and cervical) may help aid in further proper diagnosis of

sport-related concussions, but also the proper treatment and plan of care for athlete's that have sustained a sport-related concussion. Without such trajectories and intervention strategies, athletes may be likely to suffer from prolonged recovery (Broglio et al., 2015). Current sport-related concussion assessment tools, including the Side Assessment of Concussion (SAC), Sport Concussion Assessment Tool-3 (SCAT-3), Balance Error Scoring System (BESS) and similar tests fail to comprehensively address vestibular and ocular system dysfunction, which can result in missed findings that are common during an athlete's evaluation.

In addition, eye-tracking protocols and vision have been used in the assessment of sport-related concussion and have been effective in identifying objective abnormalities in eye movement (Cifu et al., 2015; Heitger et al., 2006). These vision tools that were utilized have consisted of laboratory ocular technology and equipment, not readily available on the sideline. This lead to the implementation of the King-Devick test in concussion protocols. In fact, a concussion consensus statement recently recommended visual assessment involving the King-Devick (KD) test and clinical reaction times (McCrory et al., 2013). The KD test has been shown as an effective test to help recognize ocular motor dysfunction in athletes who have suffered a sport-related concussion. In fact, similar to the VOMS ability to help detect concussions, incorporation of the KD test into a multi-disciplinary concussion assessment, captured 100% of sport-related concussions, whereas the SAC and BESS combined to miss 10% of sport-related concussions in one study (Marinides et al., 2014). Another study found that the KD had the greatest capacity to distinguish 12 concussions from 14 controls compared to a gait assessment and the SAC test (Leong et al., 2015). Very little research has been conducted examining vestibulo-ocular assessments, which is further warranted, especially in youth athletes.

It has been previously documented that sex differences occur in sport-related concussion incidence, with female athletes sustaining a greater number of concussions than male athletes who participate in similar sports such as soccer, basketball, and baseball/softball (Covassin, Swanik, & Sachs, 2003; Hootman, Dick, & Agel, 2007; Gessel et al., 2007; Lincoln et al., 2011; Marar et al., 2012). More recently, researchers have investigated sex differences in concussion outcomes, with female athletes reporting more symptoms at both baseline and post-concussion assessments (Frommer et al., 2011; Brown, Elsass, Miller, Reed, & Reneker, 2015; Covassin et al., 2006; Covassin et al., 2007; Kontos, Schatz, Covassin, Henry, Pardini, & Collins, 2012). Moreover, female sex has been identified one of the latest consensus statement as a factor that influences symptoms and sport-related concussion assessment (McCroory et al. 2013). With increasing numbers of female athletes in sports, understanding the role of sex is needed. If it is not known how an individual, especially a female who may have different baseline scores than a male, it is difficult to determine whether their post-concussion levels of performance on concussion assessments is due to the concussion itself, or the variability of the sex of the individual, especially if compared to normative data. These sex differences may be attributed to a female athlete's menstruation (Covassin et al., 2006), biomechanical and strength deficits as compared to male athletes (Barnes, Cooper, Kirkendall, McDermott, Jordan, & Garrett, 1998) or even physiological differences in hormonal systems and cerebral organization (Broshek et al., 2005).

Concussion literature has predominantly focused on high school, collegiate, and professional adult athletes, with a growing concern by parents, coaches, and health care professionals regarding the youth population. Youth individuals are extremely vulnerable to concussion as they are engaged in critical periods of physical, physiological, and cognitive

development. These developmental changes affect strength, postural stability, and decision-making in regard to risk-taking behaviors, especially in contact sports (Centers for Disease Control and Prevention, 2010; McKeever & Schatz, 2003). Youth concussion baseline assessment is recommended annually due to the developmental changes mentioned above (Broglio et al., 2014), but with most elementary, junior high and youth program sports not directly working with an athletic trainer or physician, this presents a great challenge. This current study aimed to investigate baseline assessments in youth athletes on the vestibular ocular motor screening (VOMS) and KD assessments, since very little research has been done in these assessment tools. Also, since it has been suggested that females and males may differ on sport-related outcomes, as well as athletes with a history of concussion (Covassin et al., 2006; Covassin, Moran, & Wilhelm, 2013), this current study examined sex differences and concussion history on VOMS and KD assessment.

1.2 Significance of the Problem

Vestibular assessment may provide important information when recognizing, monitoring and managing sport-related concussion. First, initial findings have indicate that areas of the vestibular system, such as the vestibular-spinal system, suffers from impairment after concussion, with nearly 40% of concussed individuals, reporting these deficits (Covassin, Elbin, Harris, Parker, & Kontos, 2012; Guskiewicz, Ross, & Marshall, 2001; Kontos, Elbin, Schatz, Covassin, Henry, Pardini, & Collins, 2012). While the vestibular-spinal unit of the vestibular system has been well studied, an emerging area in concussion literature is the role of the vestibular-ocular system in sport-related concussion.

Vestibular-assessment in sport-related concussion has previously been addressed using static vestibular-spinal balance assessment, such as the Balance Error Scoring System (BESS) or

Sensory Organization Test (SOT) (Guskiewicz, 2001; Nashner, Black, & Wald, 1982). Researchers and concussion experts at the University of Pittsburgh Medical Center (UPMC) Sports Concussion Program developed a new brief screening tool called the VOMS, a valid and consistent tool that requires minimal equipment, to enhance current multidisciplinary approaches to sport-related concussion assessment and clinical care (Mucha, Collins, Elbin, Furman, Tourtman-Eneski, & Dewolf et al., 2014). The VOMS is a brief concussion assessment tool, which assesses vestibular and ocular motor impairments via patient-reported symptom provocation. A series of 7 tests are conducted, with patients verbally rating their severity in headache, dizziness, nausea, and foginess symptoms on a scale of 0 (none) to 10 (most severe) after each test.

One of the first studies to investigate the VOMS examined its internal consistency and validity as a brief clinical screening tool in sport-related concussion (Mucha et al., 2014). Preliminary findings revealed that the VOMS had a high internal consistency ($\alpha=.92$) and moderate validity, making it a useful tool for screening sport-related concussion. This study examined differences in concussed and control individuals, aged 9-18 years. On the VOMS assessment, the control participants averaged 0.1 on symptom severity for all of the VOMS tests. The concussed individuals scored significantly worse than the control participants, reporting a higher symptom severity (range 2.1-3.7) for each of the VOMS tests. Further investigation into the VOMS is needed in all areas of sport-related concussion research, specifically normative baseline data in youth populations and any confounding factors such as sex, age, and history of concussion.

Using select components of the VOMS, researchers assessed vestibulo-ocular dysfunction in pediatric athletes with sport-related concussion and post-concussion syndrome

(PCS) (Ellis, Cordingley, Vis, Reimer, Leiter, & Russell, 2015). It was reported that athletes who suffered from sport-related concussion and had vestibular dysfunction, as determined by parts of the VOMS assessment, were 4-times more likely to develop post-concussion syndrome; however, these VOMS domains were only used to determine if the athlete suffered vestibular dysfunction, and not a representation of true symptom provocation throughout a four-item symptom cluster used in VOMS.

Another key aspect of the vestibular system is its joint function with the ocular motor system. While the VOMS assessment has ocular domains, it is recommended that pursuit eye movement and near-point convergence distance, in addition to saccades, should be included in any ocular assessments for concussion (Mucha et al., 2014). The KD test, which is a number naming ocular motor processing and reaction time test, may also be beneficial in ocular assessment for concussion (King et al., 2013; Galetta et al., 2011; Leong, Balcher, Galetta, Evans, Gimre, & Watt, 2014; King, Gissane, Hume, & Flaws, 2015).

The KD test has been utilized by researchers to investigate its use in sport-related concussion. When compared to a baseline assessment, the amount of time that it takes an athlete to read the sequence of test cards in the KD test increases significantly (Vartiainen et al., 2014). Previous literature has reported that any change from baseline performance greater than three or more seconds, has been identified as a possibility of a concussive injury (King, Brughelli, Hume, & Gissane, 2013; King, Clark, & Gissane, 2012; King, Gissane, Hume, & Flaws, 2015). Galetta and colleagues (2011) investigated KD assessment post-concussion in college football, soccer, and basketball athletes. After concussion, KD reaction test times increased (i.e., worse performance) by an average of 8.3 seconds from their baseline assessment, indicating that saccadic eye movement and ocular motor processing and reaction time is inhibited following

concussion. Similar results were reported by Leong and colleagues (2014), who noted a 5.2 second increase in KD reaction times as compared to baseline, following sport-related concussion in collegiate football players. Both of these studies were very limited due to a small number of concussed athletes, 10 and 11 respectively, as well as not including a diverse college sport population.

In an attempt to provide normative baseline reference values on the KD assessment, professional men's ice hockey players completed the KD test prior to their athletic season (Vartiainen, Holm, Peltonen, Luoto, Iverson, & Hokkanen, 2014). The overall test times were similar to previous research (Galletta et al., 2011; Leong et al., 2014, King et al., 2015); however they also found that professional ice hockey athletes with a history of concussion do not differ at baseline from those without a history of concussion. These results are not a true representation of the youth population or any population outside of professional athletes and also do not account for any sex differences that may occur. Baseline normative data is needed in all levels of sport (i.e., youth, middle school, high school), across all sports and sexes to be able to make age specific normative comparisons.

It may also be beneficial to examine associations between the VOMS and KD performance, as both tests share similar functions and properties of the vestibulo-ocular system. The KD test has been investigated for its associations with neurocognitive assessment to help better understand concussion assessment and management (Vernau, Grady, Goodman, Wiebe, Basta, and Park et al., 2015). Slower reaction times on the KD assessment were associated with lower scores on visual performance on a neurocognitive assessment. By coupling an oculo-motor and eye motility assessment, like the KD test, with a vestibulo-ocular motor assessment, such as

the VOMS, impacts that truly affect both the vestibular-and ocular systems may be better understood.

Symptom reporting can be a very useful indicator of concussion severity and prevalence of symptoms both before and after injury (Erlanger et al., 2003; Lovell et al., 2010), but often differ depending on age and sex (Covassin, Elbin, Harris, Parker, & Kontos, 2012; McCrory, Collie, Anderson, & Davis, 2004; Preiss-Farzanegan, Chapman, Wong, Wu, & Bazarian, 2009; Lovell, Iverson, Collins, Podell, Johnston, Pardini, & Pardini et al., 2010). Previous investigation into sex differences has predominantly examined high school and collegiate athletes, creating a need for further investigation to conclude whether or not these sex differences occur at the youth level. Brooks and colleagues (2015) investigated baseline symptom reporting in adolescent athletes aged 13-18 years, with female athletes reporting more cognitive-sensory and sleep arousal symptoms than male athletes.; however, this study did not investigate a true youth population as many individuals in this sample were of high school age, leaving little knowledge of sex differences below the ages of 13years. By investigating youth athletes on the VOMS, a better understanding on youth symptom reporting at baseline will help be established and also understand if youth have any symptom provocation from vestibular ocular assessment. Since it has been reported that females tend to perform better than males on baseline neurocognitive assessment tests of visual memory, processing speed and reaction time (Covassin, Elbin, Kontos, & Larson, 2010), further investigation is warranted to determine if these sex differences occur with other concussion tests, specifically the VOMS and KD tests.

Therefore, the aim of the current study was to provide normative data on the VOMS and KD tests for youth athletes, ages 8-14. This study also aimed to investigate sex differences on these tests, as sex has been reported to effect symptoms and sport-related concussion assessment.

With the results of Vernau and colleagues (2015) indicating that associations were reported between KD test performance and neurocognitive assessment, similar ocular associations may be recognized with other assessments. Therefore, it may be beneficial to examine the relationship between KD test performance and VOMS ocular motor assessment in the youth athlete population.

1.3 Purpose of the Study

The purpose of the current study was to investigate sex differences on the VOMS and KD tests among youth athletes. A secondary purpose of this study was to examine the relationship between KD test performance and ocular performance on the VOMS assessment. This study also served to provide normative data for youth athletes.

1.4 Specific Aims

SA1: To provide normative data for youth athletes on VOMS and KD assessment.

1.5 Hypotheses

H1: Youth female athletes will self-report more baseline concussion symptoms than youth male athletes on the VOMS baseline symptom assessment.

H2: Youth female athletes will self-report more symptoms on the VOMS subscales than youth male athletes.

H3: Youth male athletes will have a faster KD reaction time score than youth female athletes.

H4: There will be a positive relationship between KD reaction time and ocular motor symptom provocation on the VOMS assessment.

1.6 Exploratory Questions

EQ1: Will there be differences in VOMS symptom provocation in youth athletes with a history of concussion?

EQ2: Will there be differences in KD reaction time in youth athletes with a history of concussion?

EQ3: Will there be differences in VOMS symptom provocation in youth athletes with a diagnosed learning disability?

EQ4: Will there be differences in KD reaction time in youth athletes with a diagnosed learning disability?

1.7 Operational Definition of Terms

Baseline Assessment: An assessment to establish the individual athlete's "normal" pre-injury performance and to provide the most reliable benchmark against which to measure post-injury recovery (Guskiewicz et al., 2004)

Concussion: A complex pathophysiological process affecting the brain, induced by biomechanical forces (McCrory et al., 2013).

Convergence: Movement of both eye sight lines to focus on a common target.

Dizziness: A symptom of feeling faint, lightheaded, or unstable.

Fogginess: A symptom of feeling blurred or slowed down as if in a fog.

Headache: A symptom of feeling pain in the head.

King-Devick (KD) Test: A measure of processing speed, visual tracking, and saccadic eye movement via rapid number naming (Vartiainen et al., 2014).

Nausea: A symptom of feeling sick or urge to vomit.

Near-Point Convergence (NPC): Measured distance between an individual's nose and the point of convergence.

Self-Reported Symptoms: Symptoms that are subjectively told to a clinician or researcher from an individual before, during or after evaluation.

Vestibular Ocular Motor Screening (VOMS): A concussion test developed to assess vestibular and ocular impairments via patient reported symptom provocation (Mucha et al., 2014).

Vestibulo-Ocular Reflex: Human body reflex functioning to maintain a steady image on the retina when the head is moving (Jones, Jones, Mills, & Gaines, 2009).

Vestibular System: Human body system responsible for sensing motion of the head and maintaining stability of images on the retina and postural control during that motion (Schubert & Minor, 2004).

Youth Athlete: Athletes who are currently in the late childhood (8-12 years) and early adolescent (10-14 years) age classifications and participate on an organizational sports team.

1.8 Limitations and Assumptions

The current study was limited by the following: (a) the ability of participants to accurately and honestly self-report symptoms of headache, dizziness, nausea, and fogginess on the VOMS assessment. False or inaccurate responses may threaten validity and reliability of VOMS data. This is defined as the Hawthorne Effect; which is an alteration in behavior or performance resulting from the awareness of being involved in a research study (Campbell, Maxey, & Watson, 1995). In addition, the state of Michigan has undergone drastic increases in concussion awareness among athletes, parents, and coaches, which may increase the likelihood that underreported symptoms, as they know concussion-like symptoms mandates removal from play, and that intentionally performing more poorly than normal may avoid detection of a concussion, (b) The ability of participants to put forth maximum effort on the KD test, as also threatened by the Hawthorne Effect, (c) selection bias due to employing a convenient rather than random sample, (d) all participants were located from the mid-Michigan and (e) data were

collected during multiple points of the year and in different settings (indoors, sideline, etc.).

Lastly, some athletes completed their baseline testing at various points of practice, depending on practice schedules and availability. In this study, it was assumed that athletes would honestly and accurately report all symptoms and give maximum effort throughout the testing.

CHAPTER 2

REVIEW OF THE LITERATURE

This review of literature provides a comprehensive summary of the research on sport-related concussion, particularly in youth athletes, as well as vestibular-ocular assessment in sport-related concussion. The definition of concussion is discussed first, followed by an overview of epidemiology, risk factors, and sex differences in sport-related concussion, including youth athletes. Next, the evaluation and assessment of sport-related concussion and their findings are discussed, as well as the development and importance of vestibular-ocular assessment in athletes. Key studies that have shaped our current understanding of sport-related concussion in youth athletes, as well as assessment are thoroughly reviewed. This chapter concludes with a summary of relevant gaps in the literature and the purposes of the present study.

2.1 Definition of Concussion

For many decades, there has been a debate over the definition of sport-related concussion. Furthermore, sports-related concussion is used interchangeably with head injury or mild traumatic brain injury (mTBI) in the literature. Currently, the National Athletic Trainers' Association (NATA) position statement for managing sport-related concussion and the American Academy of Neurology (AAN) utilize the same definition of concussion, which states a concussion is a "trauma-induced alteration in mental status that may or may not involve loss of consciousness (Broglia et al, 2014; AAN, 1997). Previous recommendations may have utilized terms "ding", "getting one's bell rung", "clearing the cobwebs", and other such phrases in reference to concussion (Guskiewicz et al., 2004); however, these terms should not be used as it decreases the severity of the injury.

A much more well-defined and accepted definition is from the consensus statement from the 4th International Conference on Concussion in Sport. The panel defined concussion as “a complex pathophysiological process affecting the brain, induced by biomechanical forces” (McCroory et al., 2013). A concussion may be caused by either a direct blow to the head, face, neck, or elsewhere on the body, with an impulsive force transmitted to the head. Concussion typically results in a rapid onset of short-lived impairment of neurological function and neuropathological changes, but the acute symptoms reflect a functional disturbance, rather than a structural injury. These clinical symptoms may or may not involve a loss of consciousness (McCroory et al., 2013).

2.2 Pathophysiology of Concussion

Immediately following a biomechanical injury to the brain, alterations in release of neurotransmitters, ion influx, cell permeability, cellular metabolism, and cerebral blood flow occur (Giza & Hovda, 2001; Ellis, Leddy, & Willer, 2014; Signoretti, Lazzarino, Tavazzi, & Vagnozzi, 2011). Upon impact, extracellular concentrations of glutamate increase and other neurotransmitters are released, resulting in the massive influx of calcium and sodium into neurons and surrounding glial cells (Choe, Babikian, DiFiori, Hovada, & Giza, 2012) (See Figure 1). This ion influx causes sodium and potassium pumps to work harder by requiring progressive amounts of adenosine triphosphate (ATP) to restore the neuronal membrane to its normal potential, maintaining homeostasis, which results in a dramatic jump in glucose metabolism (Giza & Hovda, 2001). This hypermetabolism results in an energy crisis that is a likely factor in post-concussion vulnerability. After this hypermetabolism, metabolism and glucose utilization slows; however, increasing levels of calcium may still worsen this energy crisis and cause energy failure, due to mitochondrial oxidative metabolism dysfunction (Ellis,

Leddy, & Willer, 2014; Choe et al., 2012; Giza & Hovda, 2001). This decrease in glucose and ATP leaves the membrane weakened and disrupted brain plasticity. Cerebral blood flow, which is tightly coupled with cerebral metabolism, becomes impaired, leading to cerebral hyperfusion, and leaving the brain more susceptible to injury. This metabolic cascade of events, along with the cognitive impairments, reflects on concussion being mostly a functional, rather than a structural abnormality.

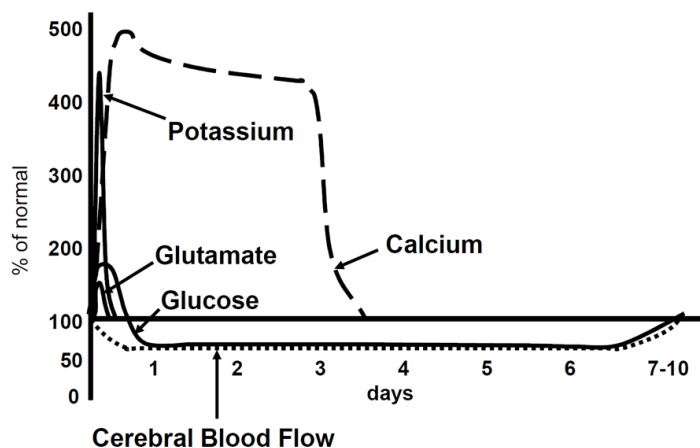


Figure 1. The time course of the neurometabolic cascade following experimental concussion.

From “The New Neurometabolic Cascade of Concussion,” by C. Giza and D. Hovda, 2014, *Neurosurgery*, 75, p. 30. Reprinted with permission.

2.3 Epidemiology and Prevalence of Concussion in Sport

Very few researchers have examined injury rates and prevalence in collegiate and high school athletes. Some authors have shown that the incidence of sport-related concussion is higher in high school athletes, as compared to collegiate athletes (Guskiewicz, Weaver, Padua, & Garrett, 2000). Previous work conducted by Hootman and colleagues (2007), examined injury data from the National Collegiate Athletic Association (NCAA) Injury Surveillance System

(ISS) over a 16-year period (1988-2004), across 17 sports. The researchers reported that sport-related concussions made up approximately 5% of all total injuries in the surveillance system. Women's ice hockey (18.3%), men's ice hockey (7.9%) and women's lacrosse (6.3%) had the largest incidence of sport-related concussion, followed by football (6.0% regular season v. 5.6% spring season), men's lacrosse (6.0%), women's soccer (5.3%) and women's basketball (4.7%). Respectively, women's ice hockey, men's ice hockey, football and women's soccer had the highest injury rate (See Table 1).

More recent research from the NCAA ISS from 2009-2014 reported similar incidence's by sport, however wrestling had the highest overall injury rate of all NCAA sports (10.92 concussions per 10,000 athlete exposures (AE), followed by men's ice hockey (7.91 / 10,000 AE), women's ice hockey (7.5 / 10,000 AE), men's football (6.71 / 10,000 AE), and women's soccer (6.31 / 10,000 AE) (Zuckerman, Kerr, Yengo-Kahn, Wasserman, Covassin, & Soloman, 2015). While sports like wrestling, men's and women's basketball, field hockey, women's softball, and men's hockey have seen increases in concussion incidence since 2007, these sports also have recently been reported to have a high portion of recurrent concussions. Men's ice hockey (20.1% of recurrent concussions), field hockey (13.3%), men's basketball (13.1%), women's soccer (12.5%), women's basketball (10.3%), and women's softball (9.4), were the sports with the highest percentage of recurrent concussions.

Gessel et al. (2007) examined the epidemiology and incidence of sport-related concussion at the collegiate level, while also providing updates at the high school level. While examining data from the 2005-2006 academic year via the NCAA ISS, sport-related concussion represented approximately 6% of all total injuries. This study did not include men's and women's ice hockey, nor men's and women's lacrosse. Across nine sports, women's soccer (6.3 / 10,000

AE), football (6.1 / 10,000 AE), women's basketball (4.3 / 10,000 AE) and men's soccer (4.9 / 10,000 AE) were the four highest sports in regard to prevalence of sport-related concussion.

These researchers also reported similar trends at the high school level using data from the National High School Reporting Information Online (RIO) system during the 2005-2006 academic years, with sport-related concussion representing 8.9% of all total injuries (Gessel et al., 2007). Football at the high school level resulted in the highest percentage of sport-related concussion injuries with over half of the total number of sport-related concussions. In estimation with the national prevalence, 40.5% of sport-related concussions were from football, with an injury rate of 4.7 per 10,000 AEs. Girls' soccer (3.6 / 10,000 AE), boys' soccer (2.2 / 10,000 AE), and girls' basketball (2.1 / 10,000 AE) followed in their respective order. Injury rates per high school sport are provided in Table 1.

More recent epidemiological data gathered at the high school level reflects that sport-related concussion represents approximately 13.2% of all total injuries (Marar, Fields, & Comstock, 2012). The data using the National High School RIO surveillance system during the 2008-2010 academic years (Table 1) revealed that a majority of sport-related concussions resulted from playing football (47.1%), followed by girls' soccer (8.2%), wrestling (5.8%), and girls' basketball (5.5%). Football had the highest injury rate at 6.4 concussions per 10,000 AEs, followed by boys' ice hockey (5.4 / 10,000 AE), boys' lacrosse (4.0 / 10,000 AE), girls' lacrosse (3.5 / 10,000 AE), girls' soccer (3.4 / 10,000 AE), and girls' basketball (2.1 / 10,000 AE).

Lincoln and colleagues (2011) conducted an investigation looking at sport-related concussion incidence in high school athletes over an 11-year period from 1997-1998 to 2007-2008 academic years. Using the data collected from a large public school system, sport-related

concussions in football had an injury rate of 6.0 concussions per 10,000 AE. Girl's soccer (3.5 / 10,000 AE), boys' lacrosse (3.0 / 10,000 AE), girls' lacrosse (2.0 / 10,000 AE), boys' soccer (1.7 / 10,000 AE), wrestling (1.7 / 10,000 AE), and girls' basketball (1.6 / 10,000 AE) were the other sports with higher rates of concussion. While football had the highest rate for sport-related concussion, the rate was 11 times that of baseball, which had the lowest rate of sport-related concussion in boys' sports. Among girls' sports, soccer had the highest proportion of overall sport-related concussion, which was 6 times that of cheerleading, the girls' sport with the lowest incidence of sport-related concussion.

In another study using the high school RIO system, Rechel, Yard, and Comstock (2008) reported injury patterns of high school games and practices. Sport-related concussions represented 12% of all game and competition injuries and 5.9% of all practice injuries. Competition and game concussions were more likely to occur in girls' basketball (19.0%), girls' soccer (18.8%), boys' soccer (15.6%), and football (12.0%). In girls' soccer, 9.7% of concussions occurred in practice, 8.7% of concussions were sustained during softball practice, and 8.7% of concussions during football practice. Swenson, Yard, Fields, and Comstock (2008) conducted a similar study investigating recurrent injury patterns in high school athletes. Sport-related concussions consisted of 11.6% of recurrent injuries, the third most common recurrent injury, only behind ligament sprains (34.9%) and muscle strains (13.3%). Sport-related concussions made up a larger portion of recurrent injury in girls' soccer (19.1%), boys' soccer (13.8%), girls' basketball (13.7%), and football (12.4%).

National injury surveillance systems and databases have provided researchers with prodigious amounts of sport-related concussion data and information. A majority of that data has

only been examined in collegiate and high school athletics, leaving the epidemiology, prevalence, and injury rates of youth athletes, greatly unstudied.

Table 1.

Sport-Related Concussion Injury Rates per 10,000 Athlete Exposures

| Sport | Authors, Year | | | | | |
|---------------------|----------------------|--------------------------|----------------------------|----------------------|--------------------|--------------------------|
| | Hootman et al., 2007 | Gessel et al., 2007 (HS) | Gessel et al., 2007 (NCAA) | Lincoln et al., 2011 | Marar et al., 2012 | Zucker- man et al., 2015 |
| Football | 3.7 | 4.7 | 6.1 | 6.0 | 6.4 | 6.7 |
| Soccer (Male) | 2.8 | 2.2 | 4.9 | 1.7 | 1.9 | 3.4 |
| Soccer (Female) | 4.1 | 3.6 | 6.3 | 3.5 | 3.4 | 6.3 |
| Basketball (Male) | 1.6 | 0.7 | 2.7 | 1.0 | 1.6 | 3.8 |
| Basketball (Female) | 2.2 | 2.1 | 4.3 | 1.6 | 2.1 | 5.9 |
| Baseball | 0.7 | 0.5 | 0.9 | 0.6 | 0.5 | 0.9 |
| Softball | 1.4 | 0.7 | 1.9 | 1.1 | 1.6 | 3.2 |
| Wrestling | 2.5 | 1.8 | 4.2 | 1.7 | 2.2 | 10.9 |
| Field Hockey | 1.8 | N/A | N/A | 1.0 | 2.2 | 4.0 |
| Gymnastics | 1.6 | N/A | N/A | N/A | N/A | 2.6 |
| Lacrosse (Male) | 2.6 | N/A | N/A | 3.0 | 4.0 | 3.1 |
| Lacrosse (Female) | 2.5 | N/A | N/A | 2.0 | 3.5 | 5.2 |
| Hockey (Male) | 4.1 | N/A | N/A | N/A | 5.4 | 7.9 |
| Hockey (Female) | 9.1 | N/A | N/A | N/A | N/A | 7.5 |

Note: HS refers to Gessel et al. (2007) published rates in high school athletes. NCAA refers to Gessel et al. (2007) published rates in collegiate athletes.

2.4 Epidemiology and Prevalence of Sport-Related Concussion in Youth Athletes

Youth athlete sport-related concussion injury data cannot be monitored and examined through major databases such as the NCAA ISS and the National High School RIO, due to the nature of typically being in elementary or middle school settings without an athletic trainer or physician on staff, or being run through a community, where medical health care professionals are not affiliated with the league. This makes tracking and updating the youth athlete sport-related concussion data very difficult.

One study that examined the injury rate of sport-related concussion in youth football athletes ages 8 to 12 years old reported the overall rate of sport-related concussion was 1.76 concussions per 1,000 AE (Kontos, 2013). The practice injury rate was 0.24 concussions per 1,000 athlete exposures and the game injury rate was 6.16 concussions per 1,000 AE. Discrepancies between practice and game injury rates can be attributed due to the greater contact and impact in the game, which is often eliminated or decreased in practice. Youth football players ages 11-12 were 2.9 times more likely to suffer a sport-related concussion than the individuals aged 8-10 years old. This trend can be attributed to the older players being bigger, faster, and stronger than their younger counterparts, as well as engaging in more contact and tackling. Of the sport-related concussions suffered, 45% were from head to head contact, whereas only 5% from head to ground contact and 5% head to body contact.

Dompier and colleagues (2015) examined the incidence of concussions during both practice and competition in athletes 5-23 years of age during the 2012 and 2013 football seasons. Sport-related concussions comprised of 9.6% of all injuries in youth football athletes, whereas sport-related concussions accounted for 4.0% and 8.0% of all injuries in high school and college football athletes, respectively. The practice injury rate of youth football athletes was 0.59/ 1,000

AE and the game injury rate was 2.38/ 1,000 AE. Interestingly, there were no reported concussions in youth athletes age 7 or below. Also, the lower practice rate may possibly be attributed to fewer number of players per team as compared to high school and college football teams, as well as the fewer amount of weekly practices and shorter seasons.

USA Football commissioned its Youth Football Player Safety Surveillance Study in 2012 with Datalys Center for Sports Injury Research and Prevention to examine injury rates in youth football (Kerr et al., 2015). During the 2012-2013 football season, 4,000 players ages 5-14 participated in the study. Results determined that 4.3% of players in the study sustained a sport-related concussion, with no catastrophic head or neck injuries reported in the 2-year span. General injury data revealed that the injury risk was lowest among the youngest athletes and gradually increased with age, but no youth athletes aged 7 or younger sustained a sport-related concussion.

Previous research has examined sport-related concussion in youth athletes through databases and surveillance systems from emergency room and hospital visits (Kelly, Lissel, Rowe, Vincenten, & Voaklander, 2001; Boyce & Quigley, 2003; Bakhos, Lockhart, Myers, & Linakis, 2010; Meehan & Mannix, 2010). Kelly et al. (2001) and Boyce and Quigley (2003) both reported that sport-related concussion in youth athletes accounted for 3%-8% of all sport-related injuries presented at a large Canadian city emergency department. Analysis of emergency room and hospital databases in the United States reported that concussions in 8-19 year olds resulted in more than 500,000 emergency room visits, with approximately half occurring from sport participation (Bakhos et al., 2010). Of the athletes ages 8-13 who reported to the emergency room with a concussion, 58% of those emergency visits were from a sport-related mechanism, whereas youth athletes ages 14-19 had a 46% sport-related mechanism for concussion.

A similar study by Meehan and Mannix (2010) analyzed the National Hospital Ambulatory Medical Care Survey, which reported 144,000 emergency visits for concussion between 2002-2006 in youth individuals. Youth individuals aged 5-19 had a sport-related mechanism in 30% of the emergency room visits. Youths aged 5-14 accounted for 42% of those visits, whereas 15-19 year olds accounted for 40% of emergency room visits (Meehan & Mannix, 2010).

These large amounts of hospital and emergency room visits may be due to the fact that an athletic trainer or physician does not cover most youth sports, so the immediate decision for evaluation and treatment is at the closest hospital. These numbers may also be underestimated, as it is evident that nearly half of sport-related concussions in American high school football go unreported (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). This immense underreporting may be attributed to a lack of initial recognition by athletes, coaches, parents, and health care professionals, a lack of medical follow-up, or the fear of reporting concussion due to implications of playing time or desire to play through the injury (Colvin, Mullen, Lovell, West, Collins, & Groh, 2008). While epidemiological and prevalence data is a major aspect of sport-related concussion literature, it may be of more beneficial to specifically understand the factors associated with the risk and pathology of sport-related concussion in adult and youth athletes.

2.5 Risk Factors for Sport-Related Concussion

Epidemiological and injury rate data provides a clear perspective of which sports place athletes more at risk than others for sustaining a sport-related concussion. While epidemiological data may also provide important data regarding mechanisms for sport-related concussion, other risk factors for sport-related concussion, such as history of previous injury, age, and sex still remain key underlying factors.

2.5.1 History of concussion. Like many sport-related injuries, the best predictor of risk and injury, is a history of previous or similar injury. In regard to sport-related concussion, the likelihood of obtaining a sport-related concussion increases after each concussive episode. In a study of collegiate football players, Guskiewicz et al. (2003) found that athletes with a history of one previous concussion were 1.5 times more likely to sustain a second concussion in football than those players with no history of concussion. Individuals with a history of two previous concussions were 2.8 times more likely to sustain a concussion than players with no reported history of concussion. Finally, athletes with a history of three or more concussions were 3.4 times more likely to sustain a concussion as compared with athletes with no history of concussion. Of the sport-related concussions in this study, 91.7% of repeat concussions occurred within 10 days of the first concussion. While this study helped provide data on the risk of sustaining subsequent concussions, this study only focused on sport-related concussion in collegiate athletes, leaving the risk for repeat concussion in younger athletes, undetermined.

A similar study among high school and collegiate football players reported that athletes, who sustained one sport-related concussion in season, were 3 times more likely to sustain a second sport-related concussion in that same season than athletes with no previous concussion (Guskiewicz, Weaver, Padua, & Garrett, 2000). These athletes who sustained a concussion were also more likely to have more symptoms with recurrent concussion, as there was an association between recurrent concussion and onset of symptoms (Guskiewicz et al., 2000). In this study, 30.8% of injured players returned to competition that same day and 20% of athletes never came out of the game. Since this study, new concussion regulations and rules warrant immediate removal from play if there is a suspected concussion and prohibit high school athletes from returning to play the same day as a suspected concussion (Broglio et al., 2014). With many

athletes returning to sport participation, this may have placed athletes at a greater risk for subsequent concussion, as compared to athletes who have rested and progressed through a return to play protocol. This study did help to address concussion history and risk for subsequent concussion in high school football players, but it is still unknown if these data remains true for other sports and even youth athletes, not yet participating at the high school level.

A study that involves Canadian university football and male and female soccer athletes reported similar risks for repeat concussion (Delaney, Lacroix, Leclerc, & Johnston, 2002). In this study, 84.6% of football athletes and 81.7% of soccer athletes reported a history of more than one concussion. In fact, of all concussed football athletes, 17% reported a history of 3 concussions, 11% reported a history of 4 concussions, 5.7% reported a history of 5 concussions, 17% reported a history of 6-10 concussions, and 10% reported a history of greater than 10 previous concussions. Of the concussed soccer athletes, 18% reported 3 previous concussions, 9.5% reported 4 previous concussions, 15% reported 5 previous concussions, 9.5% reported 6-10 previous concussions and 2.4% reported greater than 10 previous concussions. It is unknown whether all concussions were sport-related concussions from their current sport participation and whether or not these athletes were honest about their concussion history. In a sample of just collegiate football and soccer athletes, non-contact sports and sports with lower concussion rates were not examined.

Covassin and colleagues (2008) found that collegiate athletes with a history of 2 or more concussions performed worse than athletes without a history of concussion on verbal memory and reaction time at 5 days post-concussion. Iverson and colleagues (2004) also reported similar findings, with high school and collegiate athletes reporting a history of concussion performing worse on memory tasks as compared to athletes with no previous history of concussion; however

this study only utilized a small sample of 38 athletes, 19 with a history of concussion and 19 without a history of concussion.

Further investigation into neurocognitive assessment and concussion has revealed that athletes with a history of 3 or more concussions were still impaired on verbal memory and reaction time at 8 days post-injury, as compared to their baseline score (Covassin, Moran, and Wilhelm, 2013). Athletes with a history of 2 concussions were still impaired at 3 days post-injury on verbal memory, and still impaired at 8 days post-injury on reaction time. Athletes with 1 previous concussion were impaired on verbal memory and reaction time at 3 days post-injury. This study only took into account high school and collegiate athletes, further emphasizing the need for investigation of how concussion history and recurring concussion effects youth sport athletes.

Considering that by the start of high school, 54% of student athletes have reported a history of concussion, there should be increased alertness to youth sport athletes and their risk for recurrent concussion (Field, Collins, Lovell, & Maroon, 2003). Very little research has examined the effects of concussion history at the youth level. Valovich McLeod, Bay, Lam, and Chhabra (2012) examined baseline values on the Sport Concussion Assessment Tool 2 (SCAT2), a popular tool used in concussion assessment, in high school athletes with an average age of 15 years old. Individuals with a history of concussion scored significantly worse on the SCAT2 than individuals with no history of concussion. Also, 88.7% of athletes with a history of concussion reported at least one baseline symptom as compared to 79.5% of athletes with no history of concussion. One of the main limitations to the study was that the study only included high school athletes, who happened to have an average age of 15 years old, but still does not provide

evidence for the youth population ages 14 and below and only provides data on the SCAT2 and not other concussion assessment tools.

Alsalaheen and colleagues (2015) investigated differences on King-Devick (KD) reaction time scores among high school football players with a history of concussion. Of the 45 athletes with a reported history of concussion, no sex differences were noted when compared to the 112 athletes without a history of concussion. This study only included male participants, and did not control for age, in addition to having a 2:1 non-concussion history to concussion history ratio.

With ever changing assessment protocols and development of concussion assessment tools, it is important to constantly measure the effects of concussion history to maintain valid and reliable data, especially in youth athletes, where research is lacking. Very little research has examined youth athletes ages 5 to 14, who participate in sport. It is also important to be aware that athletes may be at more risk for these subsequent concussions immediately after returning to play, therefore, these athletes with a history of concussion may benefit from a more conservative assessment, management, and return to play.

2.5.2 Age. While sport-related concussion risk in professional, collegiate and high school athletes has been demonstrated, the risk for sport-related concussion in youth athletes is currently unknown. Exploration into age as a risk factor of concussion has aimed at examining biological and physiological factors that may predispose youth athletes to a single and recurrent concussion. While the adult brain has been fully developed and operative for everyday life, the child's brain is still going through its process of development, both structurally and operationally for skills such as concentration, memory, problem-solving tasks and cognition (Hunt & Ferrara, 2009).

The youth athlete's structural frame may also predispose the athlete to greater risk or susceptibility of sustaining a concussion. Growing individuals have an immature central nervous

system, resulting in a larger head-to-body ratio, thinner frontal and temporal cranial bones (Webbe & Barth, 2003; McKeever & Schatz, 2003; Buzzini & Guskiewicz, 2006). Within the cranial bones, lies the brain, which is encompassed with a larger subarachnoid space, allowing more room for the brain to move around inside of the skull, as well as differences in cerebral blood volume and ongoing myelination (McKeever & Schatz, 2003; Webbe & Barth, 2003; Giedd, 2008). Children also have less developed and weaker neck and shoulder musculature, which contributes to the lack and inefficiency of energy dissipation and attenuation to the rest of the body, placing more energy at or above the cervical and head region (Buzzini & Guskiewicz, 2006). As these children continue through puberty and have continual growth spurts, non-proportional gains in weight and mass, as compared to neck and shoulder strength, increase locomotive forces that may place the head and neck at an extreme risk (Buzzini & Guskiewicz, 2006).

As compared to a fully developed adult brain, the adolescent and growing brain may respond differently to head impacts and recovery. Motion capture, mechanical analysis, accelerometer, and crash test dummy data all point to similar acceleration, deceleration, and rotational forces in children, which can generate forces that may damage brain tissue and neural factors (Barth, Freeman, Broshek, & Varney, 2001). Daniel, Rowson, and Duma (2012) investigated head impact exposure in youth football athletes using accelerometer and impact helmet data. While youth athletes take less contact and impact over a season than high school and collegiate athletes, high-level impacts (>80g force) were witnessed in youth football, which have been measured in adult football, some resulting in concussion. This trend is similar to severe impacts at the collegiate football level, despite the nature of the youth football game being slower and with players having less body mass (Rowson & Duma, 2011). Impacts to the side of

the helmet and to the front of the helmet, 36% and 31% respectively, were the most common sites of impact, which is where the adolescent cranial bones are thinner and less developed.

In the event of head impact or trauma, diffuse cerebral swelling with delayed catastrophic deterioration may occur from repeated concussive brain injury, in the phenomenon known as second impact syndrome (Cantu & Gean, 2010; McCrory, 2001; McCrory & Berkovic, 1998; Snoek, Minderhoud, & Wilmink, 1984). While episodes of second impact syndrome have only been reported in case studies, all cases have occurred in adolescent individuals, which exemplifies the risk in the immature, developing brain and individual.

Valovich McLeod and colleagues (2012) found baseline differences in age on the SCAT2 concussion tool among high school athletes. Ninth graders, who are typically 14 or 15 years old, scored significantly worse on SCAT2 total scores than 11th graders, typically 16 or 17 years old, and 12th graders, who are typically 17 or 18 years old. Further investigation revealed that 9th graders scored worse than 10th-12th graders on immediate memory, concentration, and delayed recall tasks of the Standardized Assessment of Concussion (SAC) subsections of the SCAT2. Ninth graders also had worse scores on balance assessment, as measured on the Balance Error Scoring System (BESS) test. This data helps support that idea that age may have an effect on concussion assessment. While this study examined high school athletes, Glaviano, Benson, Goodkin, Broshek, and Saliba (2015) investigated SCAT2 assessment in middle and high school athletes. Twelve year olds performed significantly worse on concentration scores, as measured by the SAC subsection of the SCAT2, than 15 and 18 year old athletes at baseline. Twelve-year-old athletes also had lower percentages of correct responses on the 5 digit and 6 digit SAC concentration, along with reciting the months backwards task. No differences were found on

BESS scores with 12-year-old athletes, which further warrant the need for more research in these younger athletes.

Other researchers attempted to find differences in age by examining balance control differences between adolescents and young adults (Howell, Osternig, & Chou, 2014). Howell and colleagues examined 38 concussed (19 adolescent, 19 young adult) and 38 match-controlled adolescent (average age of 15) and young adults (average age of 20) on gait balance control measures of whole body center of mass (COM) medial and lateral displacement, and anterior velocity. The results indicated that immediately after sport-related concussion, and throughout a 2-month post-injury period (1 week, 2 weeks, 1 month and 2 months), adolescent athletes with sport-related concussion displayed greater total COM medial-lateral displacement and peak velocity as compared to their control. Young adults displayed less peak COM anterior velocity than their control group. Overall, adolescent athletes demonstrated greater gait and balance deficits than did young adults as compared to their controls. This was the first study to examine age-related gait and balance control deficits after concussion, which suggests that adolescents with sport-related concussion may have greater deficits, which may require a more cautious management plan for younger athletes. Howell and colleagues (2014) also examined balance and gait, a pathway of the vestibular-spinal reflex. Creation of newer assessment tools, such as the Vestibular/Ocular Motor Screening (VOMS) assessment, help to assess the vestibular-ocular reflex, separate from the vestibular-spinal reflex. One of the purposes of this current study was to determine if there is age related differences in the vestibular-ocular assessment, which may be likely as balance and gait are a common factor in the vestibular system.

Benedict and colleagues (2015) investigated performance on the King-Devick concussion-screening tool, a rapid number reading ocular reaction time test in patients who had

received care for a concussion at a university medical center. In regard to age, it was discovered that patients who were aged 60 and older produced worse reading and reaction time scores on the assessment as compared to patients who were 30 years of age and younger. While worse times were associated with older age, it is believed that younger children may have slower scores at baseline which improve with increasing age during their teenage years (Galetta et al., 2015).

Authors have stated that these age differences not only represent a gradual improvement with age and need for annual baseline testing (Glaviano, Benson, Goodkin, Broshek, & Saliba, 2015; Broglio et al., 2014, Guskiewicz & Valovich McLeod, 2011; McCrory, Collie, Anderson, & Davis, 2004), but the need for developing separate instruments and assessment tools, that may be designed for younger individuals, such as the Child SCAT3 (Glaviano, Benson, Goodkin, Broshek, & Saliba, 2015). With previous research in these youth athletes only investigating the SCAT2 and BESS assessments, more research is needed in newer concussion assessment tools, such as the King-Devick (KD) assessment and VOMS assessment.

2.5.3 Sex. Researchers conducting epidemiological studies have also identified differences in sport-related concussion incidence between male and female athletes at the collegiate and high school levels (Covassin, Swanik, & Sachs, 2003; Gessel et al., 2007; Marar et al., 2012; Hootman, Dick, & Agel, 2007; Lincoln, Caswell, Almquist, Dunn, Norris, & Hinton, 2011; Zuckerman, Kerr, Yengo-Kahn, Wasserman, Covassin, & Solomon, 2015). Female athletes tend to be at a greater risk for sustaining a sport-related concussion in sports played by both sexes, such as soccer, basketball, baseball/softball and ice hockey (Gessel et al., 2007; Marar et al., 2012; Lincoln et al., 2012; Colvin, Mullen, Lovell, West, Collins, & Groh, 2009). Covassin and colleagues (2003) specifically examined sex differences in college athletes from 1997-2000 and discovered similar findings in regard to females having greater likelihood of

sport-related concussion. Covassin and colleagues reported that female soccer players sustained significantly more sport-related concussions than male soccer players. Female basketball players were also more likely to sustain a sport-related concussion than male basketball players.

While sex differences have been reported in sport-related concussion incidence and injury rates, prevalence of symptoms pre-and post-injury can also differ based on sex. Previous research on head injury and traumatic brain injury has stated that females may respond differently than males (Frommer et al., 2011, Brown, Elsass, Miller, Reed, & Reneker, 2015; Kontos, Elbin, Schatz, Covassin, Henry, Pardini, & Collins, 2012; Covassin et al., 2006).

Brown and colleagues (2015) reported that at baseline, females had higher odds than males of reporting vision problems, hearing problems, headache, migraine, difficulty concentrating, sleep disturbances, and emotional disturbances than males. At baseline and post-concussion, females had overall greater symptom scores. Most recently revised symptoms clusters also reported sex differences, as females report higher symptoms on all post-concussion symptom clusters than male participants in cognitive-sensory (i.e., sensitivity to light, difficulty concentrating), sleep-arousal (i.e., drowsiness, sleeping less than normal), vestibular-somatic (i.e., headache, dizziness), and affective symptoms (i.e., sadness, nervousness) (Kontos, Elbin, Schatz, Covassin, Henry, Pardini, & Collins, 2012). This study examined sex differences in high school and college athletes, but with an average age of 15 years old, results cannot be directly implied to youth athletes.

In 2006, Covassin et al. investigated sex differences in baseline sport-related concussion symptoms in collegiate athletes and found that females differed from males in their baseline reporting. At baseline, females had higher symptom scores than males in headache, nausea, fatigue, sleeping more than usual, drowsiness, sensitivity to light, sensitivity to noise, sadness,

nervousness, feeling more emotional, difficulty concentrating, visual problems, and total symptom scores. While investigating baseline differences in neuropsychological function, Covassin and colleagues (2006) also reported that females scored better on baseline verbal memory, while males scored better on visual memory. Again, this data is only representative of collegiate athletes at baseline, whereas this current study attempts to compare sex differences in youth athletes in regard to a vestibular symptom cluster consisting of headache, dizziness, nausea, and foggiess.

Similarly, Brooks and colleagues (2015) discovered that adolescent athletes, ages 13-18 years, displayed sex differences in baseline concussion assessment. Females reported more cognitive-sensory and sleep-arousal symptoms than males. This current research study adds to this youth population, specifically in younger athletes down to age of 8 years old.

As female and male athletes exhibit sex differences at baseline, studies have been conducted to examine these same measures during post-concussion assessment. Covassin, Schatz, and Swank (2007) examined post-concussion symptoms and neurocognitive function in concussed collegiate athletes. Sex differences were noted on visual memory tasks as concussed females performed worse than concussed males. Sex differences may play a key and pivotal role in concussion risk, therefore it is necessary to be aware of not only which sports may cause risk, but factors directly related to females.

In 2011, Frommer and colleagues examined sport-related concussion symptoms, resolution time and return to sport between male and female high school athletes. While no sex differences were observed in the number of symptoms, resolution time, or return to play, there were differences in the types of symptoms that athletes reported. Males reported amnesia and confusion/disorientation more often than females, whereas females reported more drowsiness

and sensitivity to noise. One major flaw of this study was the nearly 3:1 male to female ratio, which could have had some effect on the results. Furthermore, this data only investigated high school athletes, so it remains unclear as to whether or not these results hold true for younger, youth sport athletes.

Broshek and colleagues (2005) also examined sex differences following sport-related concussion in high school and collegiate athletes. Females reported higher symptoms post-concussion than males, but also were found to be cognitively impaired 1.7 times more frequently than males following concussion. Females also had significantly greater declines from pre-season baseline levels in simple and complex reaction times. Covassin, Elbin, Kontos, and Larson (2010) examined neurocognitive baseline sex differences in high school and college athletes with a history of concussion. Females were found to have performed better on verbal memory tasks than males overall, and females with a history of 2 and 3 or more concussions also performed better on verbal memory tasks than males with a history of 2 and 3 or more concussions. Females with a history of 3 or more concussions also performed better on visual memory, while females in general also performed better on processing speed and reaction time as compared to their male counterparts. These findings help emphasize sex difference considerations when examining the effects of concussion. This study only includes high school and collegiate athletes, which leaves investigators curious as to whether these sex differences occur in the youth athlete population.

More recent research has investigated sex differences post-concussion on symptom reporting and vestibular-oculomotor impairment in a multimodal clinical assessment study (Henry, Elbin, Collins, Marchetti, Kontos, 2016). Using a recently developed version of the Vestibular-Ocular Motor Screening (VOMS) assessment and a brief interview, it was discovered

that male participants exhibited lower overall mean dizziness scores at 2 and 4 weeks post-concussion, as compared to females. Males also displayed lower overall VOMS symptom scores at week 1 and 2 post-concussion as compared to females. This study used a modified version of the VOMS assessment and only provides an understanding of sex differences over time from post-concussion assessment. Kontos and colleagues (2016) also used the VOMS assessment to examine the associated risk of sex on baseline scores in college athletes. Sex differences revealed that female athletes were 2.99-times more likely to report greater than 1 symptom score above clinical cutoff levels. More research is needed on sex differences on VOMS subscale scoring at baseline in youth athletes.

It has been suggested that these sex differences may occur for many reasons. First, females may report with more symptoms than males, specifically headache, nausea, sadness and feeling more emotional due to the female athlete's menstrual cycle (Covassin et al., 2006). In terms of concussion incidence, female athletes may be at greater risk for concussion due to the possibility of being a smaller size and having weaker neck muscles than male athletes (Barnes, Cooper, Kirkendall, McDermott, Jordan, & Garrett, 1998). It has also been hypothesized that female athletes may also be less skilled at protecting their heads from injury than male athletes (Boden, Kirkendall, & Garrett, 1998). In sports such as soccer, style of play may impact risk concussion as female soccer athletes may be more likely to head the ball than male soccer players do and could be at risk due to a greater ball to head size ratio (Barnes et al., 1998).

Overall, being aware of risk factors for concussion such as sex and how females and males differ is vital for injury recognition and concussion assessment. This information also helps promote awareness to researchers, clinicians, and medical professionals about how to help protect against concussion. It is important to continue to examine sex differences as new

concussion tools are developed and implemented into clinical practice, such as the VOMS assessment and KD assessment. The youth population remains under-examined and further data in this population is needed to see if these sex differences do occur at younger ages and in what parameters of concussion evaluation (symptom reporting, assessment, reaction time, etc.), further adding to the purpose of this current study.

2.5.4 Learning Disability and Attention Problems. There has also been evidence that athletes with pre-existing attention problems, such as learning disability, attention deficit disorder (ADD), and attention deficit-hyperactivity disorder (ADHD), may perform differently than individuals without such attention problems on baseline concussion assessments (Elbin et al., 2013; Zuckerman, Lee, Odom, Solomon, & Sills, 2013; Brooks, Iverson, Atkins, Zafonte, & Berkner, 2015). In fact, in the latest NATA Concussion Position Statement (Broglia et al., 2014), both learning disability and ADHD are listed as factors that may modify the risk for concussion and duration of recovery.

Nelson and colleagues (2016) examined the relationship between ADHD and learning disability with self-reported symptoms. In collegiate athletes without a history of concussion, those with ADHD reported more baseline symptoms than those without ADHD and a history of concussion. More specifically, difficulty concentrating, fatigue, sleep disturbances, difficulty remembering, and balance problems were all significant reported symptoms in ADHD athletes, as compared to non-ADHD athletes. The symptoms of headache, nausea, and foginess, while measured, were not significant between groups. Mautner et al. (2015) found similar differences in individuals with ADHD on post-concussion assessment in high school athletes. Though not significant, individuals with ADHD had worse visual motor speed and reaction time than those without ADHD, post-injury.

To determine the impact that learning disability and ADHD have on baseline neurocognitive assessment, Elbin and colleagues (2015) investigated individuals who were diagnosed with a learning disability and/or ADHD along with healthy controls. Individuals with a learning disability and/or ADHD had lower verbal memory scores, visual memory scores, visual motor speed, a slower reaction time, and reported more symptoms at baseline when compared to healthy controls. Zuckerman and colleagues (2013) found similar baseline results in high school aged athletes. Individuals who were diagnosed with a learning disability and ADHD separately both had lower verbal memory scores, visual memory scores, visual motor processing speed, slower reaction time, and higher symptom scores as compared to their match controls. It has also been shown that in addition to ADHD being an identified modifier for concussion assessment, stimulant and medication use can affect symptoms and neurocognitive test performance in those individuals who suffer from ADHD (Littleton et al., 2015). Specifically, when unmedicated, individuals with ADHD perform worse than controls on psychomotor speed and worse than when medicated on reaction time. Overall, controls reported lower somatic, neurobehavioral, and cognitive symptom scores than individuals with ADHD at baseline.

Interestingly, the KD test was originally developed as a reading tool to assess the relationship between poor oculomotor function and learning disabilities (Oride, Matrutani, Rouse, & Deland, 1986). Therefore, in an understudied area, it may be valuable to understand if learning disability and ADHD diagnosis has an effect on both baseline vestibular and ocular motor performance in youth athletes.

2.6 Assessment and Management of Sport-Related Concussion

The clinical evaluation of sport-related concussion can vary considerably between individuals and even injuries. Concussion evaluation has become a multifaceted approach that

helps provide a more complete clinical profile for athletes. Athletic trainers, who serve as mostly the first medical respondent to emergency and injury situations, have made it clear that standardized concussion assessment results in a more clinically informative and accurate injury evaluation, than a normal routine clinical examination alone (Ferrara, McCrea, Peterson, & Guskiewicz, 2001).

An important step in concussion assessment and evaluation is the incorporation of baseline testing. It is recommended that ideally, all athletes should undergo a pre-season baseline assessment, especially those athletes who may be at a greater risk for concussion, based on their sport, previous history of concussion, or other factors that may warrant further assessment (Broglia et al., 2014) Gessel, Fields, Collins, Dick, & Comstock, 2007). The intent of baseline concussion testing is to aid the clinician in post-injury management process by providing both subjective and objective data that represents how the athletes feels physically, psychologically, and symptomatically, along with brain function in a normal, healthy, uninjured state. While baseline testing allows for comparison of the athlete between their normal, pre-concussed state and their post-injury state, it is important that the appropriate assessment tools are utilized, and not a sole factor in return to play decision making. Baseline testing should involve a documented neurological history with symptoms, a physical clinical examination, neurocognitive assessment, motor control assessment, and self-reported symptoms at the minimum, since concussion can have effects across multiple domains (Broglia et al., 2014). Researchers have also recently reported that vestibular and ocular system assessment may provide additional value (Hoffer, Gottshall, Moore, Balugh, & Wester, 2004; Collins, Kontos, Reynolds, Murawski, & Flu, 2013; Mucha et al., 2014).

2.6.1 Self-Reported Symptom Assessment. Self-reported symptoms, both at baseline and post-concussion, help provide subjective information about any symptoms an athlete may be experiencing and the severity, duration, or intensity of those symptoms. Self-reported symptoms in general, also provide good sensitivity to concussion injuries, but it is important that athletic trainers, clinicians, and health care professionals continue to use a multifaceted approach to concussion recognition and management (Broglio, Macciocchi, & Ferrara, M., 2007; McCrea et al., 2005).

Measuring baseline symptoms and severity is optimal in dealing with sport-related concussion. A baseline assessment allows clinicians, researchers, and health care professionals to have an accurate read of what symptoms and their intensities are normal for that athlete, in an unconcussed state. While it may be assumed that a baseline symptom assessment should not report any symptoms, individuals may present with symptoms and some severity, which further outlines the importance of a symptom assessment prior to the start of an athletic season. It has been reported that between 50% and 85% of athletes may experience at least one symptom during their baseline assessment (Valovich McLeod, Bay, Lam, & Chhabra, 2012; Shehata, Wiley, Richea, Benson, Duits, & Meeuwisse, 2009). Valovich McLeod and colleagues (2012) reported that 83% of high school males and 85.5% of high school females reported at least one symptom during baseline assessment, emphasizing the concept of obtaining symptom scores as part of a baseline assessment due to baseline symptom elicitation. Other research has found upwards of 92% of adolescent athletes reporting at least one baseline symptom, much higher than adults (Mailer, Valovich McLeod, & Bay, 2008).

The most commonly reported symptoms at baseline in normal, unconcussed athletes are headache, fatigue, difficulty concentrating, drowsiness, and trouble falling asleep (Piland et al.,

2003, Lau et al., 2011). In a study by Zimmer, Marcinak, Hibyan, and Webbe (2015), 52% of participants reported no symptoms at baseline, 34% reported 1 to 3 symptoms, 12% reported 4 to 9 symptoms, and 2% reported 10 or more symptoms. The most commonly reported baseline symptoms in this study consisted of fatigue/low energy, difficulty concentrating, drowsiness, and nervousness/anxiousness. Kontos and colleagues (2012) used symptom clusters at baseline with high school athletes and found higher baseline levels of cognitive-sensory and vestibular-somatic symptoms, but lower levels of sleep-arousal clusters than college athletes. While baseline symptoms are vital in understanding the normal symptoms of an individual, post-concussion symptoms also provide essential information in concussion assessment and management.

While these symptoms are common among athletes at baseline, during post-concussion assessment of symptoms, the most commonly self-reported symptom is a headache. Previous research has indicated that between 50-70% and even upwards of 80-95% of individuals suffering a sport-related concussion, report with a headache (Piland et al., 2003; Iverson & Lange, 2003; Makdissi et al., 2010; Erlanger et al., 2003; Guskiewicz et al., 2003, Lau et al., 2011). Guskiewicz and colleagues (2000) found that among high school and college football players, the most common reported post-concussion symptom was headache (86%), followed by dizziness (67%), confusion (59%), and disorientation (48%). Similar findings of symptoms were found in high school football players post-concussion (Lau et al., 2011). The most common concussion symptoms were headache (93%) followed by dizziness (81%), confusion (65%), fatigue (62%) and visual problems (56%).

Delaney and colleagues (2002) reported post-concussion symptoms in Canadian college football and men's and women's soccer athletes. In football athletes, headache (70%), confusion/disorientation (55%), dizziness (41%) and blurry or abnormal vision (26%) were the

most commonly reported symptoms. Men's and women's soccer athletes reported the same symptoms, but a greater percentage as compared to football, with 72% reporting headache, 56% reporting confusion/disorientation, 55% with dizziness, and 28% with blurry or abnormal vision. In another study of college athletes who suffered a concussion, dizziness was endorsed by 84% of concussed athletes, followed by headache (66%), fogginess (62%), visual disturbances (60%), and disorientation (56%) (Merritt, Rabinowitz, & Arnett, 2015). In terms of symptom severity, which was rated on a subjective scaled of 1 to 6, with a 5 or above being deemed as severe, headache was the most commonly reported severe symptom at 28.3% (Merritt, Rabinowitz, & Arnett, 2015). Visual disturbances were severe in 20.8% of concussed individuals, followed by fogginess, with 18.9% of concussed individuals having severe symptoms.

While symptom reporting for baseline and post-concussion assessment is vital in the evaluation process, some factors may impact symptom reporting. While a history of concussion has been reported as a predictor of subsequent concussion, a history of concussion may further impact symptom reporting, as those individuals may be more likely to report more total symptoms and greater symptom scores (Piland, Ferrara, Macciocchi, Broglio, & Gould, 2010; Covassin, Moran, & Wilhelm, 2013; Covassin, Stearne, & Elbin, 2008; Iverson, Echemendia, Lamarre, Brooks, & Gaetz, 2012). At baseline, Piland and colleagues (2010) found that athletes reporting a history of concussion were more likely to report more symptoms on the Head Injury Scale and greater severity of symptoms on the symptom severity scale as compared to athletes without a history of concussion. Interestingly, these authors found that athletes who reported fatigue, physical illness or acute orthopedic injury reported higher composite scores and severity than those who did not.

Covassin, Moran, and Wilhelm (2013) utilized symptoms consisting of the cognitive-migraine-fatigue, affective, somatic, and sleep clusters. While athletes with a history of concussion did not differ on baseline symptom scores, athletes with a history of 3 or more concussions self-reported more migraine-cognitive-fatigue symptom clusters at 3 and 8 days post concussion as compared to their baseline score. Further investigation is needed into whether or not history of concussion may have any effect on symptom provocation.

Another factor that may influence symptom reporting, especially in younger athletes, is the diagnosis of attention-deficit-hyperactivity disorder (ADHD) and learning disabilities. Elbin and colleagues (2013) reported that athletes aged 6 to 18 years old with ADHD, learning disabilities, or both reported a larger number of symptoms than individuals without these conditions. Individuals with ADHD or learning disabilities also performed significantly worse on verbal memory, visual memory, reaction time, and processing speed. Vaughan and colleagues (2014) found similar trends in children and adolescent athletes aged 13-19 years with ADHD, who were reported to have scored lower on cognitive tests scores, slower reaction time, and reported higher mean symptom scores than children without ADHD. Also, children with ADHD were more likely to have invalid performance on neurocognitive assessment than children without ADHD, when taken in a group setting. Researchers have also found higher symptom reporting in individuals with attention deficit disorder (ADD) during baseline testing, (Brooks et al., 2015).

One issue with self-reporting symptoms is that it is not guaranteed as a reliable source of post-concussion assessment in athletes, as many athletes may not be truthful in regard to their symptoms or severity in order to remain in play or return sooner. Additionally, younger children may not have the vocabulary or insight to describe symptoms or dysfunction (Ellis, Leddy, &

Willer, 2014). It remains pertinent to continue to use a multifaceted approach to concussion evaluation that should also include neurocognitive assessment to help objectively measure concussion assessment and management.

2.6.2 Neurocognitive Assessment. Another major area of sport-related concussion evaluation and management is neurocognitive assessment and testing. Common computer-based neurocognitive assessments such as the Automated Neuropsychological Assessment Metrics (ANAM), Cogstate Axon, Concussion Vital Signs, Headminder Concussion Resolution Index (CRI), and Immediate Post-Concussion Assessment and Cognitive Training (ImPACT) have been implemented by athletic trainers, physicians and other health care professions as part of sport-related concussion assessment. Baseline neurocognitive assessment has gained popularity and importance in sport-related concussion assessment and management. Since concussion can hinder the normal functioning of the brain, not easily seen by athletic trainers or physicians, baseline neurocognitive assessment helps provide objective measures such as attention, concentration, memory, information processing, and reaction time to better assess an athlete for brain function.

Baseline neurocognitive assessment is very useful for sport-related concussion assessment, because decreased performance occurs post-concussion (Lovell et al., 1999). Also, individual test performance may differ on the objective measures, so an individualistic and accurate normative assessment can be provided for each athlete. With these objective measures, it makes it very difficult for athletes to misreport or underreport their injury. Often times, athletes may be asymptomatic and anticipating return to play, but a neurocognitive test may aid in increased detection by capturing any cognitive differences from their baseline. This allows the athletic trainer, physicians or clinician to better determine where the athlete is in terms of their

cognitive recovery. Once an athlete is asymptomatic and has returned to baseline on their neurocognitive assessment and any other assessment tools utilize, the athlete can begin a gradual return to play protocol. Normative data for athletes is available, which can be used if there is not a baseline assessment, to see where the athlete's cognition function is compared to what is typical for the athlete's age, sex, and education level.

Neurocognitive assessment has been directly associated with vestibulo-ocular system deficits following concussion. Corwin and colleagues (2015) found that youth individuals aged 7-18 who displayed vestibular deficits had significant worse neurocognitive scores on verbal memory, reaction time, and processing speed percentile scores in addition to taking 3-times longer to complete the visual memory, verbal memory, and processing speed assessment than those with no vestibular deficits. These youth athletes were only included in this study if they reported to a local hospital for concussion evaluation, which does not allow a true representation among normal, healthy youth athletes. A similar study was conducted investigating neuropsychological test performance, but in individuals with reports of foggy, which is another common symptom is vestibular dysfunction (Iverson, Gaetz, Lovell, & Collins, 2004). Individuals that reported subjective foggy had significantly worse scores in reaction time, decreased memory performance, and slower processing speeds.

Neurocognitive concussion research highlights the importance of utilizing a multifaceted approach to concussion assessment. As individuals sometimes do not report concussion symptoms or may not be symptomatic, neurocognitive objective measures help provide data, not otherwise seen by an athletic trainer or physician. In fact, Meehan and colleagues (2012) found that athletes were 17.2% less likely to return to play within 10 days of a concussion when neurocognitive testing was used compared to without neurocognitive testing (38.5% to 55.7%).

Similarly, youth individuals aged 12-18 reported lower correlations between neurocognitive assessment data and their perception of feeling returned to baseline status (Sandel, Lovell, Kegel, Collins, & Kontos, 2013). These findings suggest that athletes may perceive to be returned to normal baseline measures, but their perceptions do not match up with the level of current neurocognitive impairment. This emphasizes the benefit of neurocognitive assessment in helping to further recognize and manage sport-related concussion. It remains vital that the clinician use appropriate and best practices to assessing and managing concussions, which should also look into assessing other systems of the body that may be affected by concussion.

2.7 Return to Sport in Concussion Injury.

Once an athlete has been diagnosed with a concussion, he or she should be removed from sport and not cleared for participation again until cleared by a physician, no sooner than the next day (Broglio et al., 2014). Once the patient no longer reports symptoms related to concussion and their clinical examination is normal, any objective assessments (SCAT3, ImPACT test, VOMS, KD, etc.) used in the examination should be repeated and compared to their baseline performance (Broglio et al., 2014). Most young adult males return to their normal baseline performance levels within 2 weeks (McCrea et al., 2003), while young female adults and younger patients may still suffer performance-wise for more than 2 weeks (Field, Collins, Lovell, & Maroon, 2003; Covassin, Elbin, Harris, Parker, & Kontos, 2012). Once the athlete has met these aforementioned criteria, an exertion progression should commence. The step-wise return to play progression (Table 2) begins with no activity, both physically and cognitively. The next step involves light aerobic activity with the intent of increasing the athlete's heart rate. The third stage consists of more sport-specific drills that do not involve head contact. These drills may involve running or skating drills related to their sport. The fourth stage advances to more complex

training drills, while still limiting contact. This stage specifically serves to increase exercise, coordination and cognitive load in the athlete. At this stage, the athlete can also resume resistance training. Following medical clearance, the athlete may participate in a full contact practice, which will help restore the athlete’s confidence. The final step is for the athlete to be fully cleared for normal game play. The athlete will progress to the next level of the exertion protocol 24 hours later, but if the athlete’s symptoms return or a decline in performance is observed, then that stage is immediately suspended and restarted 24 hours later (McCrory et al., 2013; McGrath, Dinn, Collins, Lovell, Elbin, & Kontos, 2013). An extended and more conservative return to play protocol may be necessary for youth athletes and those athletes that have been held out for an extended period of time (McCrory et al., 2013; Broglio et al., 2014). Due to potential of serious effects, understanding the epidemiology, risk factors, sex differences and assessment of sport-related concussion are critical to determine proper management, rehabilitation and timing for a safe return to play.

Table 2.

Step-Wise Return-to-Play Progression for Concussed Athletes

| Rehabilitation Stage | Physical Activity at each stage |
|--------------------------------|---|
| 1. No activity | Physical and cognitive rest |
| 2. Light aerobic exercise | Walking, swimming, stationary cycle: <70% max HR |
| 3. Sport specific exercise | Sport specific drills, no head impact activities |
| 4. Non-contact training drills | More complex training drills, resistance training |
| 5. Full-contact practice | Unrestricted training following medical clearance |
| 6. Return to play | Normal game play |

2.8 The Vestibular System

The vestibular system is a complex sensory organization, which involves communication between the peripheral vestibular apparatus, the ocular system, postural muscles, the brain stem, cerebellum, and the cortex (Khan & Chang, 2013). Very small structures in the ear make up the vestibular apparatus and help to detect head movement and gravitational forces on the body. This further allows the brain to allow the human body to maintain balance, orientation, and vision during motion (Khan & Chang, 2013).

2.8.1 Vestibular Anatomy and Physiology. The vestibular system provides information relative to head movements and positions to maintain visual stability and balance control. The vestibular system consists of special sense organs, including the retina, semi-circular canals, otolithic organs, and joint mechanoreceptors, with primary processing units that share projections to the spinal cord, autonomic nervous system, brain stem, cerebellum, thalamus, and cerebral cortex (Armstrong, McNair, & Taylor, 2008). The two main components of the vestibular system are the vestibulo-ocular reflex (VOR) and the vestibulo-spinal reflex (VSR).

The VOR regulates gaze stabilization during head movement, in both acceleration and rotation forces. This stabilization occurs from a neuron reflex arc from the semi-circular ducts to the vestibular nuclei and then to the extraocular muscles to cause eye motion in a direction opposite to head turning (Cullen & Sadeghi, 2008). When the head turns one direction, depolarization of the hair cells occurs to the side of movement, and hyperpolarization on the opposite side. This results in increased firing frequency in the vestibular nerve and impulses are sent to the superior and medial vestibular nuclei and cerebellum (Khan & Chang, 2013). This then further results in ipsilateral contraction of the medial rectus muscle, which pulls the eyes towards the nose, and contralateral contraction of the lateral rectus muscle, which moves the eyes

away from the nose laterally (Jones, Jones, Mills, & Gaines, 2009). If eye velocity and head velocity do not match, impulses are sent to the vestibular nuclei to modify its firing rate to allow the reflex to adjust to function properly (Khan & Chang, 2013).

An example of this VOR reflex and its physiology can be captured by holding an object such as your finger or an open book in front of you at a comfortable distance and moving it quickly left and right. As you increase speed, you see that the object becomes blurry or the book is not readable, once you have exceeded the pursuit capability of the oculomotor system. If you hold your finger or the book still, and rotate your head left to right, you are now able to see the object clearly, since the VOR compensates for your head movements and keeps your eyes fixed on the object (Saladin, 2007; Jones, Jones, Mills, & Gaines, 2009).

The other key component of the vestibular system is the VSR, which coordinates head, neck, and trunk positioning during body movement. This reflex involves a variety of complex connections with the macula, visual system, and axial and limb muscles by the brain stem and cerebellum to maintain posture and balance (Khan & Chang, 2013). Rotation of the head is sensed by the semi-circular ducts and transmitted to the medial vestibular nucleus. This then connects pathways to the spinal cord and activates cervical axial muscles to help coordinate head and neck motion. A secondary branch to the vestibulo-spinal reflex is the vestibulo-collic reflex, which activates neck muscles that function to stabilize the head and keep it properly oriented in space (Hain & Helminski, 2007).

The vestibular-system and more specifically, the vestibulo-ocular system, remain critical to balance, posture, vision, and compensatory head movement. While previously reported data has reflected the occurrence of dizziness, fogginess, and vision complaints (Guskiewicz, 2000;

Merritt, Rabinowitz, & Arnett, 2015; Iverson, Gaetz, Lovell, & Collins, 2004), further evaluation of athlete's vestibular-ocular reflexes may be warranted.

2.8.2 Vestibular Assessment. Examination of the vestibular system and vestibulo-ocular system should start with a thorough evaluation of vestibular related symptoms, including balance, visual, and oculomotor assessments. Saccades, convergence, and smooth pursuits are key tests in examining the ocular movements in the vestibular system, which may elicit symptoms of dizziness, blurred vision, or headache. The main component of vestibular assessment is testing of the VOR itself. This can be performed in the horizontal or vertical planes and testing either seated or standing. The tests and symptoms that elicit symptoms should be documented to help assess and analyze any further assessments, especially if being used for a baseline comparison for post-injury evaluation.

One common method to assess the VOR is the head thrust test or also commonly termed the VOR test (Schubert & Minor, 2004). The VOR test assesses the semi-circular canal function. During the VOR test, the head is flexed to 30 degrees and the patient keeps their eyes on a target, while rotating their head up to 15° each side. In the case of VOR dysfunction, the eyes move less than normal and at the end, the eyes are not looking at the target anymore. A rapid saccades test can be done immediately to bring the target back on to fovea of the eye's focus (Schubert & Minor, 2004). Other laboratory tests may be done using computerized imaging to measure the eye and movement.

Athlete trainers and health care professionals have been assessing the vestibular system for decades as a result of traumatic brain injury. In fact, vestibulo-spinal impairment and dysfunction is common within the first few days of concussion, as athletes typically report with balance issues, with nearly 40% of athletes reporting these issues in the first week (Covassin,

Elbin, Harris, Parker, & Kontos, 2012; Guskiewicz, Ross, & Marshall, 2001; Kontos, Elbin, Schatz, Covassin, Henry, Pardini, & Collins, 2012). These athletes typically recover from balance deficits and impairments within 3-5 days after injury (Guskiewicz, Ross, & Marshall, 2001; Riemann & Guskiewicz, 2000).

While the vestibular system has been previously assessed using balance and postural examinations, the two functional units of the vestibular system, the vestibulo-spinal and the vestibulo-ocular systems, have been distinguished from one another recently, based on their symptom reports. It has been reported that around 40% of concussed individuals report balance problems (Kontos et al., 2012), which presents the distinction between the vestibulo-spinal and vestibulo-ocular systems, further emphasizing the need to assess the two separately (Mucha et al., 2014)

2.8.3 Current Vestibular Literature in Sport-Related Concussion. Vestibular deficits have been previously well studied in traumatic brain injury and sport-related concussion. Previous studies have discovered evidence of vestibulo-ocular reflex deficits in military personnel with dizziness from concussion and blast injury (Hoffer, Balough, & Gottshall, 2007; Hofer, Gottshall, Moore, Balough, & Wester, 2004). Zhou and Brodsky (2015) examined vestibular testing of children, aged 8 to 18, with dizziness and balance complaints following sport-related concussion, using auditory assessment measures. Researchers used a rotational test to assess the visual vestibulo-ocular reflex, which was deemed to be an indicator of peripheral vestibular impairment. More than 90% of the children with dizziness or imbalance following concussion had at least one abnormal finding from the comprehensive balance and vestibular evaluation. While this study used laboratory assessment, results were based off of hearing loss by an audiologist. With little non-laboratory or sport-related assessment research, this current study

aims to assess the vestibular-ocular reflex with a newly developed assessment tool. These deficits are only marked by specialized signs as determined by an audiologist, with no elicitation of concussion-related symptoms.

Kaufman and colleagues (2014) used two common vestibulo-ocular examinations, the dynamic visual acuity test (DVAT) and the gaze stabilization test (GST) to examine visual acuity changes during head movement in 20 high school football athletes and 30 college football athletes. These tests are laboratory tests that have been found to be effective clinical tools in assessing vestibular dysfunction following traumatic brain injury (Goebel, Tungsiripat, Sinks, & Carmody, 2007; Gottshall, Gray, Drake, Tejidor, Hoffer, & McDonald, 2007; Peterson, 2010). This study reported that these two assessments were reliable indicators of vestibular deficit in high school and college football players at baseline. These tests cannot be done on the sideline or in a follow-up evaluation in an athletic training room due to the need for its computer based head motion sensor tools and equipment. These tests do not monitor concussion symptoms, such as headache, dizziness or foginess, which play a vital role in the vestibular system following concussion. This study also only included a small sample of male football athletes at the high school and collegiate level, leaving sex difference influence unknown.

Corwin and colleagues (2015) examined the horizontal and vertical vestibular ocular reflex (VOR) along with a neurocognitive test and balance/gait assessment in youth athletes with sport-related concussion. In this study, 81% of patients displayed vestibular deficits either on the VOR or balance and gait assessment, with 69% specifically scoring abnormally on VOR. These individuals who displayed with abnormal vestibular deficits either on the VOR or balance and gait took longer to return to school or be fully cleared for return to play. Concussion history was factored into the analysis and found that 81% of athletes with 2 or less concussions displayed

signs of vestibular dysfunction and 100% of athletes with 3 or more showed vestibular deficits. While this study implemented the VOR assessment, which is a main assessment in the VOMS, other domains were left uninvestigated, such as the smooth pursuit, saccades, convergence, which also play a major role in vestibular-ocular assessment following sport-related concussion. The authors did not report which symptoms were elicited from the VOR assessments, which is the main rating tool used in the VOMS and a main tool in concussion assessment. Also, since the data was collected retrospectively from charts, the results are limited in its ability to standardize outcomes. Further investigation into symptom provocation and a full examination on the VOMS in this youth population is warranted, along with standardized, normative values.

2.8.4 Vestibular-Ocular Motor Screening (VOMS) for Concussion. To better assess the vestibular system and dizziness in concussion, separate from the vestibular-spinal and the ocular system, researchers developed the Vestibular/Ocular Motor Screening (VOMS) assessment (Mucha et al., 2014). This tool was also developed for use as a rapid concussion assessment tool, instead of previous vestibular laboratory tests. The VOMS assessment is purported to examine patient reported symptom provocation of headache, dizziness, fogginess, and nausea in the following 5 assessments: smooth pursuit, horizontal and vertical saccades, convergence and near point convergence, horizontal vestibular ocular reflex (VOR), and visual motion sensitivity (VMS). After each assessment, the athlete rates the four symptoms (i.e., headache, dizziness, nausea, fogginess) on a scale of 0 (none) to 10 (severe) to determine if each assessment provokes symptoms. The convergence test is the only assessment comprised of a subjective symptoms reporting, but also has an objective measure in centimeters.

Mucha and colleagues (2014) examined the VOMS assessment in 64 concussed patients and 78 healthy controls, all under the age of 18. When assessing post-concussion VOMS scores

compared to a control group (Table 3) (Mucha et al., 2014), the VOMS displayed a high-predicted probability for identifying concussed patients. In regard to symptom subscales, the control had an average symptom reporting of 0.1 out of 10, on the smooth pursuit, horizontal and vertical saccades tests, convergence, VOR, and VMS and 1.9cm on the convergence assessment. The concussed athletes had an average symptom reporting score of 2.1 on the smooth pursuit, 2.5 symptom score on horizontal saccade, 2.1 symptom score on vertical saccade, 2.2 symptom score on convergence, 3.7 symptom score on VOR, 3.1 symptom score on VMS, and 5.9 cm distance on the near point convergence. All symptom-reporting scores were significantly different between concussed and controlled patients. Preliminary data also indicated that the best subset of predictors of concussion on the VOMS test were the VOR, VMS, and near point convergence distance. Age, not sex, was a significant covariate for each VOMS subscale's association with likelihood of concussions. This study helped to provide foundational data on the VOMS as a concussion assessment tool, but more research is needed in the athletic population. Additionally, it needs to be determined if any factors such age, sex, or concussion history affect VOMS baseline assessment scores.

To assess the reliability and associated risk factors, had on performance on the VOMS assessment in healthy individuals, Kontos and colleagues (2016) examined 263 non-concussed collegiate athletes. At baseline assessment, athletes had a smooth pursuit symptom score of 0.35, 0.36 for both horizontal and vertical saccades, 0.37 for the horizontal VOR, 0.35 for the vertical VOR, and 0.41 for the VMS subscale. The average NPC distance was 2.09cm. Of the sample, 89% of individuals had abnormal scores greater than or equal to a 2 symptom score of any subscale, or an NPC distance greater than or equal to 5cm. For the smooth pursuit subscale, horizontal & vertical saccades, and horizontal VOR, 7% of participants had abnormal scores

above the clinical cutoff level. The horizontal VOR subscale had 6% of participants score above the cutoff levels, while 8% of participants scored over the cutoff level on the VMS subscale. 11% of participants also produced abnormal NPC averages distance of 5cm or more. This study helped to provide VOMS values in healthy collegiate athletes; however, little is known about these values in youth and adolescent athletes.

Ellis and colleagues (2015) assessed vestibulo-ocular dysfunction in pediatric athletes with sports-related concussion using parts of the VOMS, including smooth pursuits, saccades, and the VOR, based off of vestibular or oculo-motor symptoms, to diagnose the athletes as suffering from vestibular dysfunction. With 76% of the participants having suffered from acute sports-related concussion and 24% with post-concussion syndrome, findings revealed that there were significant increases in adjusted odds (OR=4.10) of developing post-concussion syndrome in those with vestibular deficits compared to those without vestibular deficits. While this study, implemented VOMS domains such as smooth pursuits, saccades, and the VOR, these domains were not assessed for ratings of the four symptoms (headache, dizziness, nausea, fogginess) of the VOMS assessment, but instead were just used as criteria to see if athletes were symptomatic, in which they could be classified into a vestibular-dysfunctional group. With a low sample size and only 38 of female athletes, it is unsure whether or not sex differences may occur within vestibular dysfunction.

One of the main components of the VOMS assessment is the objective measure of near-point convergence (NPC), an emerging oculomotor outcome following sport related concussion. Pearce and colleagues (2015) assessed 78 concussed athletes NPC following sport-related concussion. Of the participants, 42% had presented with an abnormal (>5cm) NPC distance, with an average NPC of 12.64cm, while the participants that presented with normal NPC had an

average distance of 1.53cm. This study also examined the relationship between NPC and neurocognitive test performance. Individuals who had abnormal NPC distances following sport-related concussion also performed worse on the verbal memory, processing speed, and reaction time sections of the neurocognitive battery as compared to individuals with a normal NPC. Individuals with abnormal NPC also reported greater symptom scores on the post-concussion symptom scale. While researchers have reported that abnormal NPC measurements occur in 45% of athletes that have suffered a sport-related concussion (Mucha et al., 2014), it is estimated that abnormal NPC measurements occur in 5% of healthy individuals, with a range from 1% to 33% (Scheiman et al., 2003). Further investigation is needed in baseline NPC levels in athletes, particularly younger athletes, as well as the relationship between NPC and performance on other oculomotor concussion assessment tools.

Table 3.

Preliminary Normative Data in VOMS Domains Scores in Healthy and Concussed Individuals (Mucha et al., 2014)

| VOMS Domain | Controls (n=78) | Concussed (n=64) |
|--------------------|--------------------|---------------------|
| Smooth pursuit | 0.1 ± 0.3 | 2.1 ± 4.8 |
| Horizontal saccade | 0.1 ± 0.3 | 2.5 ± 4.8 |
| Vertical saccade | 0.1 ± 0.3 | 2.1 ± 4.6 |
| Convergence | 0.1 ± 0.3 | 2.2 ± 4.0 |
| NPC distance, cm | 1.9 ± 0.3 cm | 5.9 ± 7.7 cm |
| Horizontal VOR | 0.1 ± 0.3 | 3.7 ± 5.1 |
| VMS | 0.1 ± 0.3 | 3.1 ± 5.7 |

Note: The vertical VOR test was not conducted in this study

2.8.5 Vestibular Rehabilitation. Researchers who developed the VOMS assessment, also shed light onto the comprehensive approach to treating athletes that present with vestibulo-ocular symptoms with sport-related concussion (Collins, Kontos, Reynolds, Murawski, & Fu, 2013). As previously mentioned, the vestibular trajectory is typically characterized predominantly by symptoms of dizziness, fogginess, and nausea. Athletes suffering from vestibular dysfunction will often describe increases in symptoms when getting busier, in more stimulating environments, and rapid head movements. By conducting pre-season VOMS and symptom score assessments, it may be better understood which symptoms athletes may be more sensitive too, if any symptoms are provoked during the VOMS assessment. This may help to better understand an athlete's rehabilitation and recovery better. Collins and colleagues (2013) recommend undergoing vestibular therapy to help resolve and rehabilitate vestibular symptoms. Vestibular therapy has been proven as an effective treatment for individuals suffering from conditions such as benign paroxysmal positional vertigo (BPPV), central vestibular, peripheral vestibular, visual or proprioceptive dysfunction (Maskel, Chiarelli, & Isles, 2006; Furman & Whitney, 2000).

To support the concept of vestibular rehabilitation, Alsalaheen and colleagues (2010) examined the effects of vestibular rehabilitation on dizziness and balance recovery in children and adults suffering from concussion. Participants further broke down the descriptions of their dizziness symptoms, with the most common description of dizziness was feeling off balance (68%), followed by lightheadedness (54%), spinning (46%), nausea (38%), and sensation of motion (23%). Results indicated that children, aged 8-18, had significant recovery on dizziness severity, with vestibular rehabilitation as compared to adults over the age of 18. Children also had improvements in balance as measured by the sensory organization test, as compared to

adults. Overall, all patients undergoing vestibular rehabilitation improved on self-reported dizziness and performance measures, indicating that vestibular rehabilitation should be considered in individuals who report with dizziness and balance issues post-concussion. With further investigating into VOMS symptom reporting at baseline, the VOMS concussion assessment tool, can be integrated into vestibular rehabilitation to better assess rehabilitation improvements and return to baseline status.

Schneider and colleagues (2014) later examined the effects of vestibular rehabilitation and cervical spine therapy in concussed individuals ages 12-30. Individuals who reported with dizziness, neck pain, or headache were randomized into a treatment and control group. All groups underwent weekly sessions of therapy consisting of postural education, range of motion exercises, and cognitive and physical rest, until asymptomatic. The experimental group received cervical spine and vestibular rehabilitation. Individuals undergoing cervicovestibular rehabilitation were 10.27 times more likely to be medically cleared and returned to sport in 8 weeks than the control group. After 8 weeks of treatment, 73% of the cervicovestibular group was medically cleared as compared to 7% in the control group. This further exemplifies the benefit of vestibular rehabilitation in individuals that suffer from dizziness and vestibular related symptoms following concussion. This study was limited by a small sample size of only 15 concussed athletes in the treatment group, whom of which, 11 were male and 4 female. Sixteen athletes were in the control group with predominantly more females (9) then males (7). It remains unclear whether or not age and/or sex had any effect on cervicovestibular rehabilitation. Also, no vestibular assessments were conducted, so a specific vestibular diagnosis could not be made.

2.8.6 Ocular Assessment. A coupling association with the vestibular system is vision. In addition to symptoms of dizziness and fogginess, ocular motor impairments and visual disturbances are common after concussion, with approximately 30% of concussed athletes reporting visual problems within the first week of concussion and up to 65% of athletes having ocular motor dysfunction (Kontos et al., 2012; Capo-Aponte, Urosevich, Temme, Tarbett, & Sanghera, 2012). Other related symptoms of ocular motor impairment and dysfunction are blurry vision, diplopia, impaired eye movement, difficulty reading, dizziness, headaches, ocular pain, and poor-visual based concentration (Ciuffreda, Ludlam, & Thiagarajan, 2011). Research has demonstrated that eye movement and vision may become impaired following concussion and head injury. In traumatic brain injury, latency and inaccuracy of saccades have been noted following injury (Heitger, Anderson, & Jones, 2002). Saccadic eye movement studies in post-concussion syndrome were distinguishable from normal controls due to a greater number of errors, requiring a significantly greater number of saccades and poorer movement with longer durations to complete the test (Heitger, Jones, & Anderson, 2008). While other sport-related concussion assessment tools have been credited as reliable in detecting concussion, very few have been able to be administered on the sideline, and rapidly, creating a consensus among health care practitioners that a sport-related concussion assessment tool is needed to quickly assess and aid in sport-related concussions assessment and management.

2.8.7 Current Oculo-Motor Literature in Sport-Related Concussion. Given that ocular dysfunction is a commonly reported visual problem in individuals with head injury, investigation into the King-Devick (KD) test and its use in sport-related concussion assessment has been a growing area (Ciuffreda, Kapoor, Rutner, Suchoff, Han, & Craig, 2007). The KD is a 2-minute, sideline assessment of rapid number naming, which requires an athlete to read a series

of numbers on three sets of test cards, as quickly and efficiently as possible. The KD test aims to help screen for concussions by identifying impaired eye movement and saccades via a series of reading trials.

Galetta and colleagues (2011) were one of the first to examine the KD test and sports-related concussion, studying the effectiveness in college football, soccer and basketball athletes. All athletes conducted a pre-season baseline examination, which produced an average of 38.6 seconds to complete the test. When an individual sustained a suspected concussion, the KD test was then readministered on the sideline. The cohort of concussed athletes produced an average time of 46.9 seconds for completion, an 8.3 second slower reaction time from their baseline reaction time. In the concussion cohort, only three athletes made errors with two committing one error and one athlete committing four errors. The authors suggested that there might be a tradeoff of accuracy from concussed athletes to produce a faster completion time, with the aspirations of obtaining their baseline score. This study was limited by a concussed sample size of 10 athletes, with 9 being males and 1 female.

A similar study examined KD assessment in collegiate football athletes (Leong et al., 2015). Football athletes who suffered a sport-related concussion had significant slower times compared to their baseline times (36.5s vs 31.3s). A main limitation was that only 11 athletes sustained a suspected sport-related concussion over the period of the study, making conclusions difficult due to the small sample size.

Another study by Galetta and colleagues (2015) studied differences in KD performance between youth ice hockey and lacrosse athletes aged 5-17 years and collegiate athletes aged 18-23 years. After accounting for age, the 12 athletes who sustained a sport-related concussion

scored on average 5.2 seconds slower than their baseline scores. Again, this study was limited by the small sample size and only including male youth athletes.

Seidman and colleagues (2015) examined the effectiveness of the KD test as a concussion tool in high school football players. Three hundred and thirty seven varsity football athletes, with an average age of 15.4 years of age, had an average baseline time of 47.4 seconds. During the study, nine athletes sustained a concussion and produced an average time of 66.2 seconds on their post-injury evaluation, an 18.8 second slower time than the baseline assessment of players that did not sustain a concussion.

King, Hume, Gissane, and Clark (2015) were the first to report KD test performance in junior rugby athletes aged 9-11 years old. Of the 19 athletes in the study, a total of seven sport-related concussions were sustained. These athletes who sustained a concussion, had an average slowing of 7.4 seconds from baseline performance, on their post-injury evaluation. Overall post-injury evaluation times ranged from 3.4-23.0 second slowing, all beyond the 3-second delay cutoff in previous literature (King, Brughelli, Hume, & Gissane, 2013; King, Clark, & Gissane, 2012; King, Gissane, Hume, & Flaws, 2015). While this data included youth athletes, it only included a male population and a low sample size of 19 athletes.

Galetta and colleagues (2011) wanted to see if previous results held true in boxers and mix-martial arts (MMA) fighters who take extreme head trauma in competition. The KD test was conducted prior to and directly after each individuals fighting bout. Pre-fight data showed that all 39 participants had an average completion time of 44.6 seconds. In the 31 individuals who did not sustain any head trauma during their fight, they improved on their post-fight assessment by 1.9 seconds, whereas 8 fighters who had head trauma, scored 14 seconds slower compared to their pre-fight assessment. Interestingly, 4 fighters lost consciousness during their bout and upon

regaining consciousness and awareness completed their post-fight assessment. Those that lost consciousness scored 19.4 seconds worse than their pre-fight time. The difference in post-fight times between the individuals who received head trauma and those who lost consciousness were 5.0 seconds. In addition, there was a 23.9 second difference between those who did not suffer head trauma and those who lost consciousness. Compared with previous literature, the boxers and MMA fighters produced slower pre-fight times than concussed groups; however, this study was limited to a small number of individuals who had head trauma. These times can partly be due to nature of the tests being done pre-fight instead of pre-season, where the fighters may have had a sport-related concussion and are likely to have sustained sub-concussive forces during their training leading up to their fights.

King and colleagues (2013) examined the usefulness of the KD test in amateur rugby athletes, ages 18-26, who sustained a sport-related concussion. The amateur athletes that sustained a concussion had an average baseline performance time of 43.5 seconds. Immediately post-concussion, athletes produced a test time of 48.4 seconds, 4.9 seconds slower than baseline performance. At 3 days post-concussion, athletes produced an average time of 50.2 seconds, 6.7 second slower than baseline. At 7 days post concussion, athletes produced an average time of 48.2 seconds, 4.7 slower than baseline. Athletes performance on the KD immediately following injury, at 3 days post-injury, and 7 days post-injury were all significantly worse than their baseline performance. While not significant, after 14 days athletes still did not return to baseline, with an average test time that was 2 seconds slower than their baseline time. By 21 days post-concussion, athletes returned to their baseline performance times. These results are only applicable to male rugby players and leaves for little application to females and athletes in other sports.

King, Gissane, Hume, and Flaws (2015) also examined the usefulness of the KD test in amateur rugby athletes, reporting average age of 23.7, representing similar ages to college and professional athletes. Of the individuals who sustained a sport-related concussion, the average time post-injury was 46.5 seconds, 4.6 seconds worse than their baseline (concussion only) of 41.4 seconds. Investigators also conducted the SAC and SCAT3 assessments with all of the participants. In concussed athletes, lower scores on the SAC and SCAT3 were associated with slower times on the KD test. For every 1-point reduction in each of the SAC components, there was a corresponding decrease of 2.9 seconds in the KD test. Research suggests that this corresponding decrease occurred since saccades can be used to access cognitive domains, such as attention, spatial, and temporal orientation and working memory injuries involving the disruption of the areas involved (Galetta et al., 2013). These results are difficult to apply to younger athletes, such as high school and even youth athletes, as well as females, as a homogenous sample was used in this study.

Benedict and colleagues (2015) reported similar associations with the KD test and other concussion screening tools in patients who were examined at a concussion medical center. By investigating the use of the KD test with Symptom Severity Scale and SAC test, it was reported that individuals who produced slower KD test times were associated with higher Symptom Severity scores. Patients with slower KD times were also more likely to report symptoms of irritability, feeling more emotional, and having more severe neck pain at the time of symptom evaluation. Also, individuals who had slower KD times were also associated with lower total SAC scores and SAC immediate memory score. It is unknown whether similar relationships are apparent in younger individuals and on other baseline measures such as the VOMS assessment.

Vernau and colleagues (2015) investigated baseline associations of the KD assessment and neurocognitive assessment in youth ice hockey athletes aged 6-18. Slower ocular assessment times on the KD test were associated with lower scores on the ImPACT test, specifically visual motor speed and reaction time. Athletes also underwent near-point convergence assessment at baseline and post-concussion using the near point convergence test. Results revealed that 11.5% of participants had abnormal scores (≥ 6 cm) at baseline on the near point convergence and 14% at post-concussion. By coupling the KD test and VOMS, relationships and associations of performance may be better understood.

Tjarks and colleagues (2013) also investigated the utility of the KD test and ImPACT composite scores, but in adolescent patients, ages 12-19, who sustained a concussion. Of the 35 patients, 18 males and 17 females completed the assessments, revealing that KD test performance was directly correlated to neurocognitive performance. Following concussion, as KD times worsened, significant decreases were observed on the ImPACT composite scores on verbal memory, visual memory, visual motor speed, and reaction time. Similarly, as KD time improved following concussion, ImPACT composite scores on verbal memory, visual memory, visual motor speed, and reaction time all improved. While the ImPACT composite scores can delineate more specific measures of visual performance, KD performance does help to reflect some of these similar deficits; however, it remains unknown if similar changes are witnessed with the ocular-motor components of the VOMS assessment.

Researchers have also used the KD test to assess the reliability from pre-season baseline to post-season. Galetta et al. (2011) examined post-season test times for reliability measures as compared to baseline times. The average time for the end of the season on KD assessment was 35.1 seconds, which shows that the average athlete improved 3.5 seconds on the post-season test

compared to the baseline test, which is a normal finding due to a learning effect of how fast and efficiently the test cards can be read. Leong et al. (2014) found that in collegiate football players, there was a 1.4 second improvement from baseline (35.9 seconds) to post-season (34.5 seconds) assessment. King, Gissane, Hume, and Flaws, (2015) reported that there was an improvement of 7.6 seconds on the KD test from baseline (45.1 seconds) to post season (37.5 seconds) in amateur rugby athletes. Munce and colleagues (2014) also reported improvements from pre-season to post-season in youth football athletes. A total of 10 youth football athletes improved from 47.35 seconds at pre-season to 42.54 seconds post-season on KD reading time (Test card 1: 14.63s to 13.18, Test card 2: 15.30s to 13.80s, Test card 3: 17.42s to 15.56s). As a gradual improvement and learning effect is exhibited between baseline to post-season, age and sex differences may possibly impact results as well. This may emphasize the need to continually update baseline measures especially if athletes participate in multiple sports, across multiple seasons (i.e., participating in fall, winter and spring sports).

The KD test has illustrated its value as a tool to help better assess and manage sport-related concussions; however, most of the literature has low numbers of concussed participants. The current literature has also predominantly investigated older, collegiate, amateur, and professional athletes. The youth athlete population, as well as female athletes, seems to warrant further investigation as age and sex may impact assessment. Also, the KD test fails to evaluate other areas of ocular function. Such as pursuit and convergence which have all been found to be dysfunctional in individuals with traumatic brain injury (Capo-Aponte, Urosevich, Temme, Tarbett, & Sanghera, 2012; Ciuffreda, Kapoor, Rutner, Suchoff, Han & Craig, 2007).

2.8.8 Normative Data for the King-Devick Test. Vartiainen and colleagues (2015) reported normative reference values for professional male ice hockey athletes. One hundred and

eighty five professional hockey athletes, with the average age of 23 years old, completed a preseason baseline test to provide normative data, found below in Table 4. These results provide little applicability to non-professional athletes across other sports besides men’s ice hockey.

Table 4.

Normative Reference Values for the KD Test Trials and Test Cards (time, sec.) in Professional Male Ice Hockey Players (Vartiainen et al., 2014)

| | Mean | Super-ior | Above Avg. | Average | Below Avg. | Unusually Low | Extremely Low |
|-------------------|------|-----------|------------|-----------|------------|---------------|---------------|
| <i>Trial 1</i> | | | | | | | |
| Test Card 1 | 14.0 | <11.6 | 11.6-12.5 | 12.6-15.1 | 15.2-16.8 | 16.9-22.8 | >22.8 |
| Test Card 2 | 14.0 | <11.6 | 11.4-12.2 | 12.3-15.1 | 15.2-16.9 | 17.0-21.2 | >21.2 |
| Test Card 3 | 14.6 | <11.6 | 11.6-12.8 | 12.9-15.8 | 15.9-18.4 | 18.5-22.5 | >22.5 |
| Total Score | 42.5 | <34.5 | 34.5-37.6 | 37.7-46.2 | 46.3-51.2 | 51.3-64.5 | >64.5 |
| <i>Trial 2</i> | | | | | | | |
| Test Card 1 | 13.3 | <10.9 | 10.9-11.9 | 12.0-14.3 | 14.4-16.0 | 16.1-19.5 | >19.5 |
| Test Card 2 | 13.3 | <11.0 | 11.0-11.8 | 11.9-14.4 | 14.5-15.7 | 15.8-20.0 | >20.0 |
| Test Card 3 | 13.9 | <11.5 | 11.5-12.3 | 12.4-15.0 | 15.1-16.7 | 16.8-19.9 | >19.9 |
| Total Score | 40.4 | <33.8 | 33.8-36.3 | 36.4-43.9 | 44.0-47.7 | 47.8-59.9 | >59.9 |
| <i>Best Score</i> | | | | | | | |
| Test Card 1 | 13.3 | <11.0 | 11.0-11.9 | 12.0-14.5 | 14.6-16.0 | 16.1-18.1 | >18.1 |
| Test Card 2 | 13.3 | <11.0 | 11.0-11.8 | 11.9-14.4 | 14.5-15.8 | 15.9-19.3 | >19.3 |
| Test Card 3 | 13.8 | <11.5 | 11.5-12.2 | 12.3-15.0 | 15.1-16.7 | 16.8-19.7 | >19.7 |
| Total Score | 40.4 | <33.8 | 33.8-36.3 | 36.4-44.0 | 44.1-47.8 | 47.9-56.7 | >56.7 |

Note: Superior scores occur in <10% of sample (>90th percentile), above average scores occur in ~15% (76-90th percentile), average scores occur in ~50% (25-75th percentile), below average scores occur in ~15% (10-24th percentile), unusually low scores occur in ~8% (2-9th percentile), and extremely low scores occur in <2% (<2nd percentile).

Alsalaheen, Haines, Yorke, and Diebold (2015) reported normal reference values in high school football players aged 13-18 years old. One hundred and fifty seven participants completed pre-season baseline testing with normal reference values below in Table 5. Individuals aged 16-18 produced faster reading times than individuals aged 13-15, however that is expected as older individuals have faster (i.e., better) visual motor processing speed (Iverson et al., 2003). There were no differences in test time between individuals with a history of concussion (41.11s) and without a history of concussion (43.27s). While these results are only applicable to high school aged males, normative data needs to be examined in youth athletes for both male and female sexes.

Table 5.

Normative Reference Values and Percentile Scores (time, seconds) for the KD Test in High School American Football Players (Alsalaheen et al., 2015)

| Percentile | 5th | 10th | 30th | 50th | 70th | 90th | 95th |
|--------------------|-------|-------|-------|-------|-------|-------|-------|
| <u>13-15 years</u> | 59.11 | 51.43 | 47.93 | 43.82 | 40.99 | 35.77 | 34.16 |
| 16-18 years | 55.51 | 51.91 | 44.05 | 40.99 | 38.89 | 31.94 | 31.94 |

2.8.9 Ocular Rehabilitation. As previously reported, athletes who suffer from sport-related concussion may suffer from ocular related symptoms. The second parameter in the comprehensive approach to vestibulo-ocular motor treatment, the ocular motor trajectory, has

been characterized by localized and frontal headaches, fatigue, distractibility, difficulty with visual based classes, pressure behind the eyes, and difficulty focusing (Collins, Kontos, Reynolds, Murawski, & Fu, 2013). These symptoms may worsen with extended time looking at screens. It is recommended that proposed treatment for rehabilitation of this trajectory is vision therapy from a neuro-optometrist, or vestibular therapist.

2.9 Summary

It is apparent that from the aforementioned research that many factors may influence concussion assessment in high school collegiate and professional athletes. These factors include but are not limited to history of concussion, age, and sex. With research on sport-related concussion specific to children and adolescents being rather limited, it remains essential to continue to investigate whether a history of concussion, age, and sex affect concussion assessment in these younger developing athletes. Many athletic trainers, physicians, and health care professionals have implemented and utilized current concussion assessment tools, such as the SCAT, SAC, BESS, and ImPACT tests into their sideline and clinical concussion assessment and management. Many newer assessment tools such as the VOMS and KD tests seemed to have gained importance as newly recognized systems of the body may be impacted by sport-related concussion.

Therefore, it is imperative to examine not only the affects of these newly developed and implemented assessment tools in post-concussion, but to gain a better understanding of their baseline norms, in all ages and sexes. Finally, further insight can be gained by assessing baseline associations between concussion assessment tools to further understand how the human body ultimately functions in regard to these assessments.

CHAPTER 3

METHODOLOGY

3.1 Purpose

The purpose of the current study was to investigate sex differences on the vestibular ocular motor screening (VOMS) test and the King-Devick (KD) test among youth athletes, aged 8-14 year old. A secondary purpose of this study was to examine the relationship between KD test performance and ocular performance on the VOMS assessment. This study also served to provide normative data for youth athletes.

3.2 Research Design

This study was a prospective experimental study. The independent variable was sex of the athlete, either male or female. The variables of age (8-11 y/o and 12-14 y/o) and concussion history was used as additional independent variables for exploratory purposes. The dependent variables of this study was VOMS baseline total symptom reporting scores (i.e., headache, dizziness, nausea, fogginess), VOMS symptom subscales of smooth pursuit, saccades, near point convergence, vestibular ocular reflex, and visual motion sensitivity, and near point convergence scores. In addition, KD reaction time scores per test card and trial, along with errors were collected.

3.3 Sample Population and Participant Selection

A total of 468 youth athletes (308 males, 160 females) from the mid-Michigan area were included in the current study. Athletes were recruited from local mid-Michigan youth football and youth soccer organizations. Youth athlete ages ranged from 8-14 years.

Inclusionary criteria consisted of any athletes aged 8-14 years that were currently enrolled in participating youth sport programs, and returned the parental consent and child assent

forms. Exclusionary criteria consisted of individuals who were not enrolled in the participating youth programs, under the age of 8, over the age of 14, and any individuals who were diagnosed with a concussion in the past 6 months. Individuals who have been diagnosed with a learning disability, dyslexia, ADHD/ADD, or seizure disorder were also excluded from this study. Individuals who have undergone brain surgery, or have a severe history of intracranial pathology (e.g., subdural hematoma) as determined by a positive CT scan or MRI were also excluded from this study.

3.4 Instrumentation

The instrumentation consisted of three sections: Demographics, VOMS and KD assessment.

3.4.1 Demographic Survey. The demographic survey (see Appendix A) was used to assess variables of the participating youth athletes. In addition to sport and sex, this section included questions regarding age, concussion history, migraine history, learning disability, dyslexia, ADHD/ADD, seizure disorder, medication, and a family history of any concussion, migraines, or learning disability, dyslexia, ADHD/ADD or seizure disorder.

3.4.2 Vestibular-Ocular Motor Screening (VOMS) Assessment. Researchers and concussion experts at the University of Pittsburgh Medical Center (UPMC) Sports Concussion Program constructed the VOMS assessment (see Appendix B). A large number of expert reviewers were involved in the development of the VOMS assessment to assess vestibular and ocular motor impairments via patient-reported symptom provocation after each assessment (Mucha, Collins, Elbin, Furman et al., 2014). The VOMS consists of brief assessments in 5 domains: (1) smooth pursuits, (2) horizontal and vertical saccades, (3) convergence, (4) horizontal and vertical vestibular ocular reflex (VOR), and (5) visual motion sensitivity test

(VMS). After each domain is assessed, the patient is asked to self-report their symptoms of headache, dizziness, nausea, and foggiess on an 11-point Likert scale, ranging from 0 (none) to 10 (severe). The ocular domains (smooth pursuits, saccades, and convergence) require immediate symptom reporting following each assessment. The vestibular domains (VOR and VMS) require the participant to wait 10 seconds before reporting symptoms, to allow for any senses of blurriness or ocular impairment to clear. The reliability of the VOMS assessment has a high internal consistency, with a Cronbach alpha of .92 (Mucha et al., 2014).

The VOMS assessment began by asking the patients to rate the four baseline symptoms (headache, dizziness, nausea, foggiess) of how they presently feel at the beginning of the assessment on a scale of 0-10. Due to the concern that youth participants may have the vocabulary or insight to accurately describe symptoms (Ellis, Leddy, & Willer, 2014), each symptom was clarified with understandable terminology prior to testing. A headache was described as having pain inside the head. Dizziness was described as feeling like one was spinning, lightheaded, or unstable. Nausea was described as feeling sick to one's stomach. Foggiess was described as feeling blurred or slowed down, as if in a fog. The first domain assessed is the smooth pursuit, also known as the H-test, which tests the ability of the patient to follow a slowly moving object (See Figure 2) (Mucha et al., 2014). The patient and examiner are both seated, and the examiner holds their fingertip 3 feet in front of the patient at eye level. The patient is then instructed to keep their head still, and follow the examiners fingertip as they move it 1.5 feet to each side from the starting position, at a rate of 2 seconds to each side (Mucha et al., 2014). The target is also moved up and down at the same rate, moving 1.5 feet above and below, resembling an H-pattern. Immediately after two repetitions, the patient rates the four symptoms.

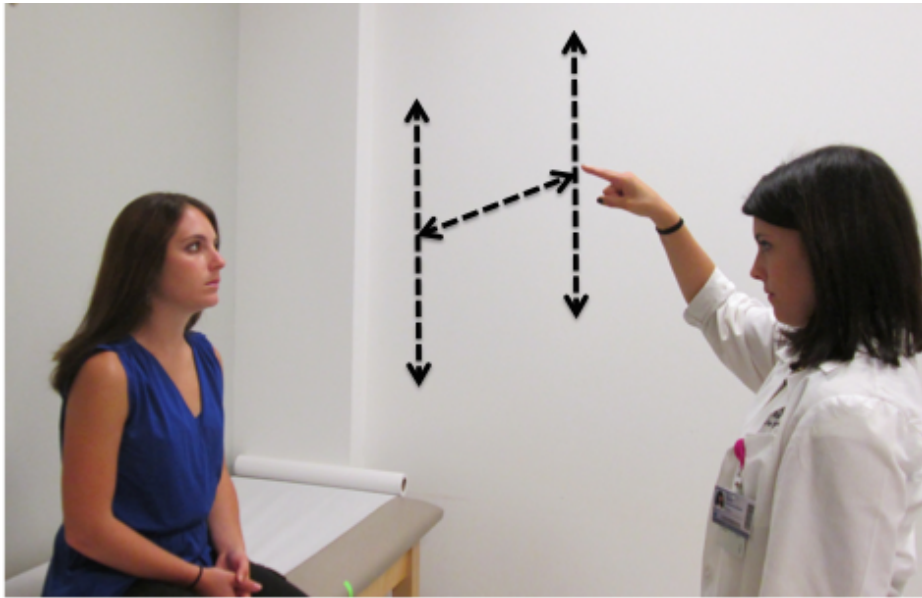


Figure 2. Smooth pursuit (H-test) VOMS domain (Mucha et al., 2014).

The second domain consists of the horizontal and vertical saccades (Figure 3). Both the horizontal and the vertical saccades test the ability of the eyes to move quickly between two targets (Mucha et al., 2014). For the horizontal saccades, the examiner holds their fingers 3 feet from the patients face, and 1.5 feet to the left and right from the patient's midline, so the patient can gaze 30 degrees to the left and 30 degrees to the right. The patient is instructed to move their eyes back and forth between the two targets 10 times, with one repetition counting when the eyes go back and forth once, without moving their head (Mucha et al., 2014). Athletes then report their symptoms on the 11-point Likert scale. After this assessment, the patient rates the four symptoms. The vertical saccade is identical, but with the patient looking 1.5 feet above and 1.5 feet below the midline. After the 10 repetitions, the four symptoms are immediately rated.

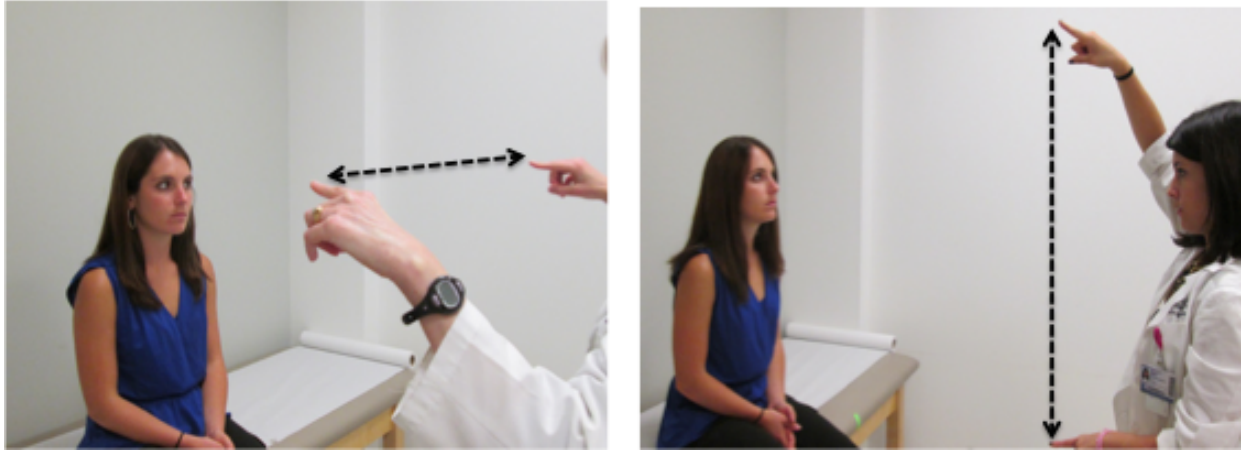


Figure 3. Horizontal (left) and vertical saccades (right) VOMS domain (Mucha et al., 2014).

The third domain of the VOMS assessment is convergence, which is both a subjective and objective test. The convergence test (Figure 4), also known as the near-point convergence (NPC), tests the ability to view an approaching near target without double vision (Mucha et al., 2014). The patient is seated and instructed to focus on a target approximately a size 14-point font, such as a pencil point or by creating an X on a tongue depressor. The patient will hold the target and slowly bring it towards the tip of their nose. The patient is then instructed to stop moving the object when they see two distinct images or when the examiner observes an outward deviation of one eye. The examiner then measures the distance from the tip of their nose to the object (i.e., tongue depressor) in centimeters. The patient then performs this test two more times, for a total of three trials, and the distance is recorded each time. After recording the trials, the four symptoms are immediately rated by the patient (Mucha et al., 2014). For the purpose of this study, the distances recorded will be averaged together to produce a total near point convergence, with $>5\text{cm}$ being abnormal (Scheiman et al., 2003).

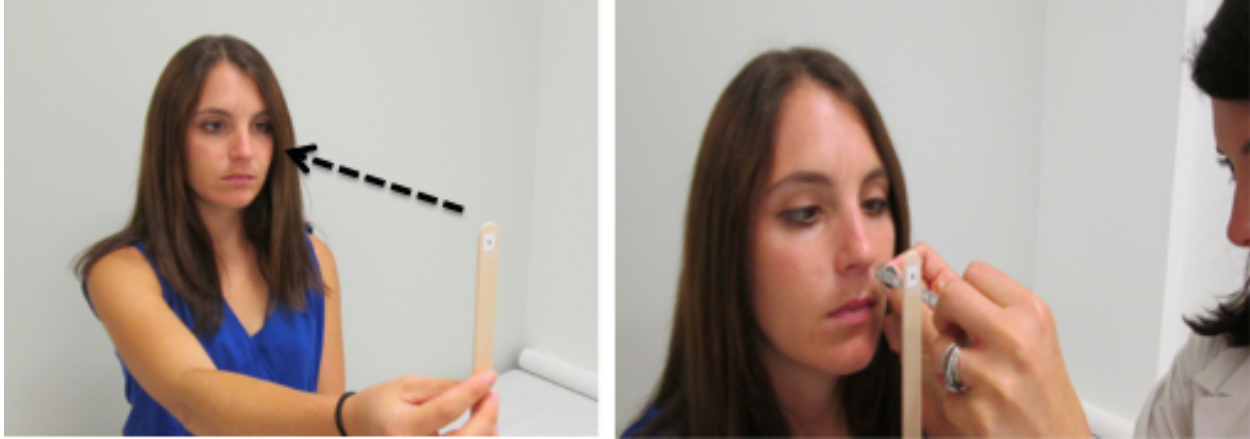


Figure 4. Near- point convergence (left) and objective measurement (right) VOMS domain (Mucha et al., 2014).

The fourth domain is the horizontal and vertical vestibular-ocular reflex (VOR) test. These tests aim to test the ability to stabilize vision as the head moves, activating the human body's actual vestibular-ocular reflex (Mucha et al., 2014). For the horizontal VOR test (see Figure 5), the patient is seated with a 14-point object, most commonly their thumb nail with their thumb up, with their arm extended in front of them (Mucha et al., 2014). The thumb and arm are held steady, as the patient is instructed to rotate their head horizontally 20 degrees each way from the midline, as if shaking head 'no', at a rate of 180bpm. The patient will perform 10 repetitions, with 1 repetition counting when the head moves back and forth to the starting position. After 10 repetitions, the participant waits 10 seconds before the four symptoms are rated. The vertical VOR test is identical, but the athlete now lifts and tucks their chin, as if nodding head 'yes', with their hand pronated and thumb pointing to the side. This test is done at an amplitude of 20 degrees up and down, and at a rate of 180bpm. After 10 repetitions, the participant waits 10 seconds and then the four symptoms are rated.



Figure 5. Horizontal (top) and vertical (bottom) vestibular ocular reflex VOMS domain (Mucha et al., 2014).

The final domain of the VOMS assessment is the visual motor sensitivity (VMS) test (See figure 6). This test is designed to test visual motion sensitivity and the ability to inhibit vestibular-induced eye movements using vision. This test is done with the patient standing with their feet shoulder width apart, begins with the patient holding their arm straight out and thumb extended as previously done in the horizontal VOR test. While focusing on their thumb, the patient rotates their head, eyes, and trunk synonymously at an amplitude of approximately 80 degrees to the left and 80 degrees to the right, at 50bpm. Unlike, the VOR test, where the patient moves their head only, while focusing their eyes on the object, this involves rotating as a unit, including their arm, as the eyes remain focused on the thumb. The patient performs a total of 5 repetitions and then after 10 seconds, rates the four symptoms.



Figure 6. Visual motion sensitivity VOMS domain (Mucha et al., 2014).

3.4.3 King-Devick (KD) assessment. The KD assessment is a brief sideline test consisting of rapid number naming, which has become popular in concussion recognition and management (Leong et al., 2015). The KD test involves reading a series of single-digit numbers from left to right, as if reading a book. The KD test begins with a demonstration card followed by 3 test cards (Figure 7) getting progressively more challenging. Participants begin by reading the demonstration card from left to right, attempting to read it as quickly as possible, but also efficiently as to not make any errors. Time is kept for each card using a stopwatch and the total KD test time is based on the cumulative time taken to read all 3 test cards. Time is only recorded when the patient is reading and not stopped or flipping cards. The test is completed two times due to a learning effect, and the baseline score is then recorded as the faster of the two trials of the three sets of cards, without making errors. If an error is committed during the trial, the test gets stopped immediately and restarted from the first test card; however, if the error is quickly corrected, the test may continue without restarting. For the purpose of this study, the time of each test card was recorded, as well as the final cumulative time. The total amount of errors committed per trial was recorded as well. The test-retest reliability for the King-Devick has been

found to be very high, with intraclass correlations of 0.97 between measurements in the absence of concussion (Galetta, Barrett, & Allen et al., 2011).

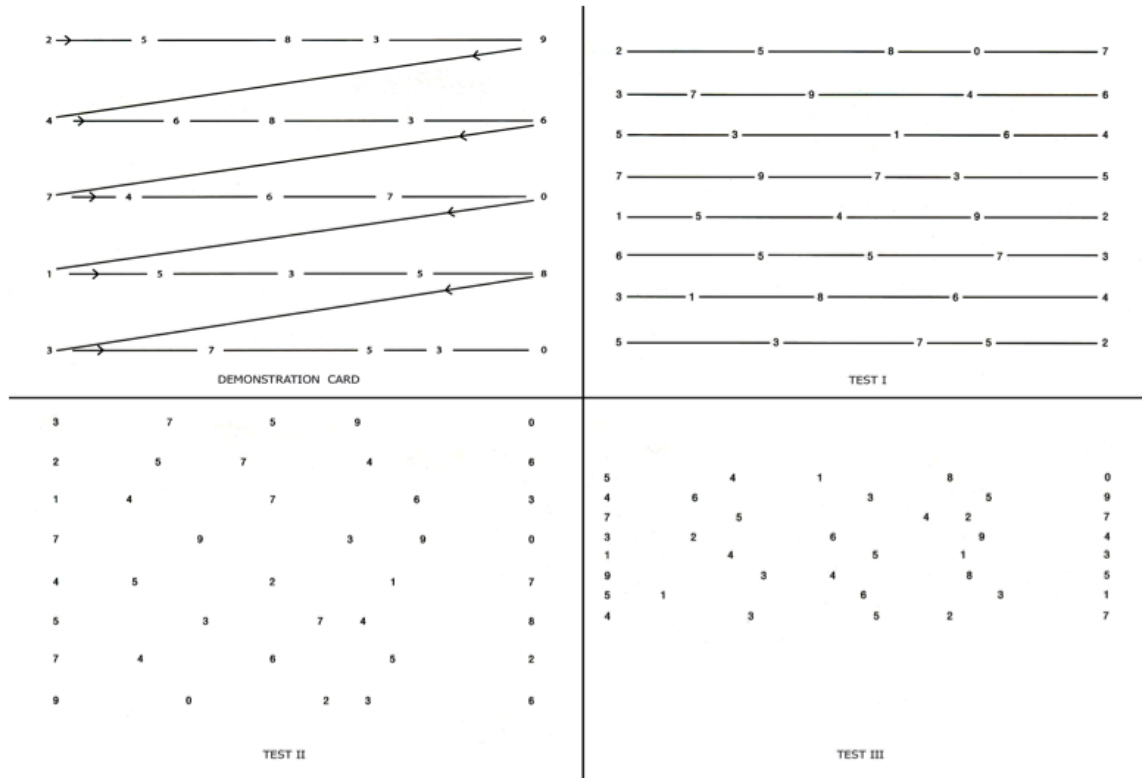


Figure 7. King-Devick test and card set (Galetta et al., 2011).

3.5 Data Collection and Management

Approval for the current study was obtained by the Institutional Review Board of Michigan State University (see Appendix C) prior to the start of data collection. Upon receiving approval, contact was made with local youth program coordinators/directors to ask for willingness of their athletics team to participate. After approval, the researcher attended pre-season parent and athlete meetings to discuss the study and distribute the consent and assent forms. Upon return of the parent consent form, child assent, and demographic survey, participants completed the assessment battery at the beginning of their respective sports season, with data collection taking place at each participating program’s venue, either indoors, outdoors

on the sideline, or in the bleachers away from the practice environment in a quiet environment. Ten individuals, consisting of certified athletic trainers and research volunteers, performed the testing. The research volunteers underwent 3 weeks of training and practice to display proficiency in testing, prior to data collection. Training consisted of demonstration of both assessments, along with a verbal script for each assessment. Participants then practiced until the lead researcher deemed them proficient as performing the test independently. The data collection took approximately 5 minutes total to complete the VOMS and KD tests. The instruments needed to complete the VOMS assessment consisted of a 14-point tool (tongue depressor), a metronome, and tape measurer. The instruments needed to complete the KD tests consisted of the test book, which contains the demonstration card and 3 sets of cards, and a stopwatch to record time. The administration of the VOMS and KD was counterbalanced to eliminate any factors that may affect performance. All data obtained were placed in a locked file box in the office of the primary investigator.

3.6 Data Analysis

General descriptive (i.e., means, standard deviation, frequencies), and inferential statistics were used to summarize all demographic data, independent variables, and outcome variables. The VOMS baseline symptoms were scored as a total score out of 40, 10 points possible for each of the four symptoms (headache, dizziness, nausea, fogginess). Each of the seven VOMS subscales (smooth pursuit, horizontal saccades, vertical saccades, convergence, horizontal VOR, vertical VOR, and the VMS) were scored out of 40, with a maximum score of 10 on each of the four symptoms (headache, dizziness, nausea, and fogginess). For the KD test, time was measured in seconds for all 3 cards across both trials, the final cumulative test time for each trial, and the fastest test trial. To control for history of concussion and learning disability analyses, match

controls were matched on sex, age, and sport for each youth athlete with a reported history of concussion or learning disability. All statistical tests were conducted with an alpha level of $\leq .05$ and analyzed using the Statistical Package for the Social Sciences (SPSS) 22.0 software.

The following specific aims, hypotheses and research questions with the appropriate statistical analysis are listed below.

Specific Aims:

SA1: To provide normative data for youth athletes on VOMS and KD assessment.

Descriptive statistics (i.e., mean, SD,) were used to analyze the normative data. Intraclass correlation coefficient (ICC) measures were used to determine associations between the two KD trials.

Hypotheses:

H1: Youth female athletes will self-report more baseline concussion symptoms than youth male athletes.

Data were analyzed using a 4 (symptom) by 2 (sex) analysis of covariance (ANCOVA) to compare differences between males and females. Age was included as a covariate because of potential differences in development that may affect symptom provocation.

H2: Youth female athletes will self-report more symptoms on the VOMS subscales than youth male athletes.

A 7 (VOMS subscales) x 2 (sex) multivariate analysis of covariance (MANCOVA), was used to analyze differences between males and females on symptom subscales. Age was included as a covariate because of potential differences in development that may affect symptom provocation.

In addition, a between sex group ANCOVA was used to analyze near-point convergence scores.

Age was included as a covariate because of potential differences in development that may affect convergence distance.

H3: Youth male athletes will perform faster on KD reaction time than youth female athletes.

A between sex group ANCOVA was used to compare differences on the KD reaction time scores. Age was included as a covariate because of potential differences in brain and cognitive development that may affect reading ability, processing, and reaction time.

H4: There will be a positive relationship between KD reaction time and ocular motor symptom provocation on the VOMS assessment.

A series of correlations were conducted to determine the relationship between KD reading time and the ocular motor subscale (smooth pursuit, saccades, convergence) symptom provocation.

Exploratory Questions:

EQ1: Will there be differences in VOMS symptom provocation in youth athletes with a history of concussion?

To determine if there were differences on VOM symptom reporting on the subscales between individuals with and without a history of concussion, individuals that had a concussion history were matched on sex, sport, and age with individuals without a history of concussion. A 7 (VOMS subscales) x 2 (concussion history, no concussion history) multivariate analysis of covariance (MANCOVA), was used to analyze differences between groups on symptom subscales. Age was included as a covariate because of potential differences in development that may affect symptom provocation. In addition, a between group ANCOVA was used to analyze near-point convergence scores. Age was included as a covariate because of potential differences in development that may affect convergence distance.

EQ2: Will there be differences in KD reaction time in youth athletes with a history of concussion?

To determine if there were differences on KD test performance between individuals with and without a history of concussion, individuals that reported a history of concussion were matched on sex, sport, and age with individuals without a history of concussion. An ANCOVA was used to determine differences, with concussion history as the independent variable and total test time as the dependent variable. Age was included as a covariate because of potential differences in brain and cognitive development that may affect reading ability, processing, and reaction time.

EQ3: Will there be differences in VOMS symptom provocation in youth athletes with a diagnosed learning disability?

To determine if athletes with a history of a learning disability, such as ADHD, ADD, seizure disorder, or dyslexia, have differences in VOMS symptom provocation than individuals without a learning disorder, those individuals who reported as being diagnosed with a learning disability were matched on sex, sport, and age with individuals that were not diagnosed with a learning disability. A 7 (VOMS subscales) x 2 (learning disability, no learning disability) multivariate analysis of covariance (MANCOVA), was used to analyze differences between groups on symptom subscales. Age was included as a covariate because of potential differences in development that may affect symptom provocation. In addition, a between group ANCOVA was used to analyze near-point convergence scores. Age was included as a covariate because of potential differences in development that may affect convergence distance.

EQ4: Will there be differences in KD reaction time in youth athletes with a diagnosed learning disability?

To determine if KD reaction time was different between individuals with and without a diagnosed learning disability, individuals with a learning disability were matched by sex, sport, and age to individuals with a learning disability. An ANCOVA was used to determine differences, with learning disability as the independent variable and total test time as the dependent variable. Age was included as a covariate because of potential differences in brain and cognitive development that may affect reading ability, processing, and reaction time.

CHAPTER 4

RESULTS

The purpose of the current study was to investigate sex differences on the Vestibular Ocular Motor Screening (VOMS) and King-Devick (KD) test among youth athletes. A secondary purpose of this study was to examine the relationship between KD test performance and ocular performance on the VOMS assessment. This study also served to provide normative data for youth athletes. This chapter includes a report of demographic information, descriptive statistics, and all main findings for each of the hypotheses and exploratory question.

4.1 Demographic Information

A total of 468 youth athletes from the mid-Michigan area were included in the current study. The mean age of the subjects was 11.0 ± 1.5 years, with a mean height of 151.3 ± 12.7 cm and 98.2 ± 31.1 pounds. Of the youth athlete participants, 5.3% (n=25) were 8 years old, 14.1% (n=66) 9 years old, 17.1% (n=80) 10 years old, 22.0% (n=103) 11 years old, 21.8% (n=102) 12 years old, 15.2% (n=71) 13 years old, and 4.5% (n=21) 14 years old. In regard to sport, 60.7% (n=284) were from soccer, with 56.7% (n=161) of those soccer athletes female and 43.3% (n=123) male. The remaining 39.3% (n=184) of participants were composed of male football athletes. Of the 468 youth athletes, 38 athletes (8.1%) reported a previous history of concussion and 30 athletes (6.4%) reported suffering from a learning disability, including ADHD, ADD, or dyslexia (see Table 6).

Table 6.

Concussion History and Learning Disability History by Sport

| | Football | Soccer |
|---------------------|----------|--------|
| Concussion Hx | | |
| 1 concussion | 8 | 26 |
| 2 concussions | 2 | 1 |
| 3 concussions | 1 | 0 |
| Learning Disability | 17 | 13 |

4.2 Descriptive Statistics

A series of descriptive statistics were conducted to help provide normative values for youth athletes aged 8-14 on the VOMS assessment (see table 7).

Table 7.

Normative VOMS Reference Mean Values

| VOMS Domain | Total (n=468) | Total Excluding Concussion History & Learning Disability (n=400) |
|--------------------|---------------|--|
| Smooth pursuit | 0.49 ± 1.62 | 0.44 ± 1.55 |
| Horizontal saccade | 0.55 ± 1.61 | 0.48 ± 1.40 |
| Vertical saccade | 0.62 ± 1.84 | 0.56 ± 1.70 |
| Convergence | 0.60 ± 2.08 | 0.52 ± 1.73 |
| NPC distance, cm | 1.58 ± 2.73 | 1.50 ± 2.59 |
| Horizontal VOR | 0.70 ± 1.90 | 0.63 ± 1.71 |
| Vertical VOR | 0.64 ± 1.81 | 0.57 ± 1.74 |
| VMS | 0.72 ± 2.11 | 0.66 ± 1.96 |

During the baseline symptom-reporting component of the VOMS assessment, 43 (9.2%) youth athletes reported at least 1 symptom severity on the four symptoms, with 26 (5.5%) reporting a 2 or more total symptom score. A total of 425 (90.8%) youth athletes reported no symptoms at baseline, prior to VOMS subscale symptom provocation tests. Interestingly, 278 (59.4%) of youth athletes reported no baseline or symptom provocation throughout the VOMS assessment, an all 0 scoring.

Referencing the VOMS cutoff scores of ≥ 2 total symptom score on any VOMS subscale and/or ≥ 5 cm on NPC average distance proposed by Mucha et al. (2015), which express a 38% and 50% increase in the probability of correctly identifying concussed patients, numerous participants reached or exceeded those cutoff scores at their baseline assessment (Table 8). More specifically, 14.7% (n=69) of youth athletes reported a ≥ 2 symptom cutoff score on 2 or more VOM subscales.

Table 8.

Number of athletes (%) Reporting Symptom Provocation at Baseline and Number of Athletes Over Cutoff Scores at Baseline (n=468)

| | Smooth Pursuit | Hor. Saccade | Ver. Saccade | Conv. | NPC (cm) | Hor. VOR | Ver. VOR | VMS |
|---------------------------|----------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| <u>Symptom</u> | 92 | 96 | 101 | 84 | 195 | 119 | 106 | 105 |
| <u>Provocation</u> | (19.6) | (20.5) | (21.5) | (17.9) | (41.6) | (25.4) | (22.6) | (22.4) |
| <u>Over cutoff scores</u> | 47 (10.0) | 52 (11.1) | 52 (11.1) | 51 (10.9) | 51 (10.9) | 63 (13.4) | 60 (12.8) | 61 (13.0) |

Note: symptom provocation is defined as reporting at least 1 symptom during assessment

A series of descriptive statistics and percentile scores were conducted to help provide normative values for youth athletes aged 8-14 by trial and card (Table 9) and on the KD assessment by age (Table 10). While excluding individuals who were diagnosed with a history of concussion or a diagnosed learning disability, the average KD reading time was 54.16 seconds,

as compared to 54.33 seconds that included participants with a diagnosed with a history of concussion or a diagnosed learning disability.

Table 9.

Normative Reference Values and Percentile Scores for the KD Test Trials and Test Cards (time, sec.) (n=468)

| Percentile | 5th | 10th | 25 th | 50th | 75 th | 90th | 95th |
|-------------------|-------|-------|------------------|-------|------------------|-------|-------|
| <i>Trial 1</i> | | | | | | | |
| Test Card 1 | 12.56 | 13.23 | 14.77 | 16.60 | 19.62 | 22.73 | 24.32 |
| Test Card 2 | 12.68 | 13.58 | 15.29 | 17.32 | 20.27 | 23.47 | 25.62 |
| Test Card 3 | 14.45 | 15.30 | 17.41 | 20.16 | 24.69 | 29.15 | 31.65 |
| Total Score | 40.52 | 43.04 | 47.70 | 54.76 | 65.40 | 73.36 | 80.96 |
| <i>Trial 2</i> | | | | | | | |
| Test Card 1 | 11.88 | 12.80 | 14.36 | 16.34 | 18.95 | 21.61 | 24.08 |
| Test Card 2 | 12.16 | 13.28 | 15.01 | 17.39 | 20.95 | 24.26 | 26.41 |
| Test Card 3 | 13.57 | 14.73 | 16.47 | 19.33 | 23.58 | 28.08 | 30.70 |
| Total Score | 38.4 | 40.52 | 46.27 | 52.90 | 62.59 | 72.57 | 77.71 |
| <i>Best Score</i> | | | | | | | |
| Test Card 1 | 11.79 | 12.78 | 14.27 | 16.10 | 18.7 | 21.36 | 23.76 |
| Test Card 2 | 12.08 | 12.98 | 14.66 | 16.87 | 19.91 | 22.99 | 24.66 |
| Test Card 3 | 13.60 | 14.70 | 16.29 | 19.16 | 23.16 | 27.58 | 29.51 |
| Total Score | 38.40 | 40.52 | 45.73 | 52.36 | 61.22 | 71.03 | 76.17 |

Note: Extremely high scores occur in 5% of sample (95th percentile), superior scores occur in 10% of sample (90th percentile), above average scores occur in 25% (75th percentile), average scores occur in ~50% (50th percentile), below average scores occur in 75% (25th percentile),

unusually low scores occur in 90% (10th percentile), and extremely low scores occur in 95% (5th percentile).

Table 10.

Normative Reference Values and Percentile Scores (total time, seconds) for the KD Test in Youth Athletes by Age Group (n=468)

| Percentile | 5th | 10th | 25th | 50th | 75th | 90th | 95th |
|-------------|-------|-------|-------|-------|-------|-------|-------|
| 8-11 years | 42.91 | 45.09 | 49.04 | 57.04 | 67.26 | 74.91 | 78.34 |
| 12-14 years | 35.95 | 38.25 | 42.25 | 47.41 | 52.78 | 61.21 | 67.45 |

In addition, to examining the baseline test-retest reliability between the first and second trials, intraclass correlation coefficient (ICC) measures were conducted. The 95% confidence intervals (CI) were calculated with the ICC values. The interpretation of the ICCs followed guidelines suggested by Baumgartner et al. (1999), where coefficients exceeding .80 indicated good reliability, coefficients between .60 and .79 indicated moderate reliability, and coefficients below .60 indicated poor reliability. The reliability of KD trials at baseline (Table 11) revealed a good overall reliability (ICC= 0.94; 95% CI: 0.93, 0.95).

Table 11.

Association Between First and Second KD Test Trials (n=468)

| | Trial 1-2 difference scores (sec.) | ICC (95% CI) |
|-------------|------------------------------------|-------------------|
| Test card 1 | 0.47 | 0.92 (0.90, 0.93) |
| Test card 2 | 0.00 | 0.91 (0.89, 0.92) |
| Test card 3 | 1.02 | 0.91 (0.89, 0.93) |
| Total score | 1.64 | 0.94 (0.93, 0.95) |

Frequency analysis revealed that the data is skewed to the right for all VOMS subscales: Smooth pursuit (skewness = 8.07), horizontal saccade (5.07), vertical saccade (5.03), convergence (6.26), NPC (2.54), horizontal VOR (4.96), vertical VOR (4.96), and VMS (4.51). Due to the large amount of no reported symptom provocation (i.e., 0), the kurtosis for the subscales ranged from 7.86 to 99.45.

When examining the correlation between each of the VOMS subscales, there was a moderate to strong correlation between all VOMS subscales, with a significant correlation between all subscales. (Table 12).

Table 12.

R-Values for Correlations Among VOMS subscales

| Subscale | SP | HS | VS | CON | HVOR | VVOR | VMS |
|----------|------|------|------|------|------|------|------|
| SP | | .834 | .831 | .794 | .659 | .682 | .603 |
| HS | .834 | | .862 | .807 | .819 | .767 | .805 |
| VS | .831 | .862 | | .865 | .869 | .867 | .865 |
| CON | .794 | .807 | .865 | | .887 | .823 | .854 |
| HVOR | .797 | .819 | .869 | .887 | | .875 | .896 |
| VVOR | .822 | .767 | .867 | .823 | .875 | | .887 |
| VMS | .752 | .805 | .865 | .854 | .896 | .887 | |

SP= Smooth pursuit, HS= horizontal saccade, VS= vertical saccade, CON= convergence, HVOR= horizontal VOR, VVOR= vertical VOR.

4.3 Evaluation of Hypotheses

H1: Youth females will self-report more baseline concussion symptoms than youth male athletes.

To examine hypothesis 1, an ANCOVA was conducted to determine if females reported more baseline concussion symptoms than male youth athletes. Results indicated no significant

difference between sex and baseline symptom reporting ($F_{(1, 465)} = 1.75; p = .186; \text{partial } \eta^2 = .004$). Females reported a lower baseline symptom mean score ($M=.011, SD=.48$) than males ($M=.27, SD=1.19$), therefore, the hypothesis that females would report more baseline symptoms is not supported.

H2: Youth female athletes will self-report more symptoms on the VOMS subscales than youth male athletes.

A MANCOVA was used to analyze differences between males and females on the 7 VOMS subscales. Results indicated that there were no significant sex differences on each of the VOMS subscales of smooth pursuit ($F_{(1, 465)} = .01; p = .90; \text{partial } \eta^2 = .00$), horizontal saccade ($F_{(1, 465)} = .10; p = .75; \text{partial } \eta^2 = .00$), vertical saccade ($F_{(1, 465)} = .04; p = .83; \text{partial } \eta^2 = .00$), convergence ($F_{(1, 465)} = .84; p = .35; \text{partial } \eta^2 = .00$), horizontal VOR ($F_{(1, 465)} = .05; p = .80; \text{partial } \eta^2 = .00$), vertical VOR ($F_{(1, 465)} = .39; p = .52; \text{partial } \eta^2 = .00$), and VMS ($F_{(1, 465)} = 1.78; p = .18; \text{partial } \eta^2 = .00$) (see Table 9).

Additionally, a between sex group ANCOVA was conducted to analyze sex differences on near-point convergence (NPC) distance. Results also revealed no significant difference between male and female NPC average distance ($F_{(1, 465)} = .13; p = .71; \text{partial } \eta^2 = .00$) (see Table 13). Therefore, the hypothesis of female youth athletes reporting more symptoms on the VOMS subscales cannot be supported.

Table 13.

Sex Differences in VOMS Subscale Mean Scores and Standard Deviation (n = 468)

| VOMS Domain | Males (n=308) | Females (n=160) |
|-------------------------------|------------------|--------------------|
| Smooth pursuit | 0.51 ± 1.79 | 0.46 ± 1.21 |
| Horizontal saccade | 0.55 ± 1.56 | 0.57 ± 1.70 |
| Vertical saccade | 0.63 ± 1.86 | 0.62 ± 1.80 |
| Convergence | 0.56 ± 1.90 | 0.69 ± 2.40 |
| NPC distance, cm ^α | 1.55 ± 2.77 | 1.65 ± 2.67 cm |
| Horizontal VOR | 0.73 ± 1.92 | 0.64 ± 1.87 |
| Vertical VOR | 0.69 ± 1.99 | 0.54 ± 1.41 |
| VMS | 0.65 ± 1.99 | 0.88 ± 2.33 |

$\alpha = p < .05$

H3: Youth male athletes will perform faster on KD reaction time than youth female athletes.

To examine hypothesis 3, a between sex ANCOVA was conducted to compare differences on KD reading time scores. Results revealed a significant difference between sex ($F_{(1, 465)} = 13.14; p = .00; \text{partial } \eta^2 = .02$). Interestingly, females ($M=50.74s, SD=11.22$) produced faster reading times than males ($M=56.20s, SD=11.27$). Therefore, the hypothesis that sex differences would occur is supported, however the hypothesis that males would produce faster times than females cannot be supported.

H4: There will be a positive relationship between KD reaction time and ocular motor symptom provocation on the VOMS assessment.

To test the hypothesis that there will be a relationship between KD performance and ocular motor performance on the VOMS assessment, a correlation was conducted. When assessing the relationship between KD reading time and symptom provocation on the ocular motor subscales of smooth pursuit ($r = .05$; $p = .21$), horizontal saccades ($r = .04$; $p = .33$), vertical saccades ($r = .09$; $p = .04$), and convergence ($r = .12$; $p = .01$) no linear relationships were noted. Despite a significant relationship between KD performance and the vertical saccades and convergence subscales, the correlation is very low.

4.4 Exploratory Questions:

EQ1: Will there be differences in VOMS symptom provocation in youth athletes with a history of concussion?

To determine if there were differences on VOM symptom reporting on the subscales between individuals with and without a history of concussion, individuals who had a concussion history were matched on sex, sport, and age with individuals without a history of concussion. A 7 x 2 MANCOVA was then conducted, which revealed no significant differences between a history of concussion and VOMS symptom provocation on each of the subscales of smooth pursuit ($F_{(1, 73)} = .36$; $p = .54$; partial $\eta^2 = .010$), horizontal saccade ($F_{(1, 73)} = .14$; $p = .70$; partial $\eta^2 = .00$), vertical saccades ($F_{(1, 55)} = .07$; $p = .78$; partial $\eta^2 = .00$), convergence ($F_{(1, 73)} = .21$; $p = .64$; partial $\eta^2 = .00$), horizontal VOR ($F_{(1, 73)} = .21$; $p = .64$; partial $\eta^2 = .00$), vertical VOR ($F_{(1, 73)} = .00$; $p = .99$; partial $\eta^2 = .00$), and VMS ($F_{(1, 73)} = .11$; $p = .73$; partial $\eta^2 = .00$). Interestingly, individuals with a concussion produced higher mean scores on all VOMS subscales as compared to their match controls who did not have a history of concussion (see table 13), although not significant. In addition, an ANCOVA revealed no significant difference between concussion history and NPC distance ($F_{(1, 73)} = .03$; $p = .84$; partial $\eta^2 = .00$). History of

concussion also had no significant effect on baseline symptoms, as recorded first on the VOMS assessment ($F_{(1, 55)} = 1.07; p = .30; \text{partial } \eta^2 = .01$).

Table 14.

Concussion History Differences on VOMS Subscale Mean Scores and Standard Deviation (n=76)

| VOMS Domain | No Concussion History (n=38) | Concussion History (n=38) |
|--------------------|---------------------------------|------------------------------|
| Smooth pursuit | 0.55 ± 1.42 | 0.79 ± 1.90 |
| Horizontal saccade | 0.84 ± 2.04 | 1.0 ± 2.74 |
| Vertical saccade | 0.95 ± 21.4 | 1.11 ± 2.77 |
| Convergence | 0.76 ± 1.99 | 1.08 ± 3.72 |
| NPC distance, cm | 1.54 ± 2.18 | 1.68 ± 3.58 cm |
| Horizontal VOR | 0.89 ± 2.19 | 1.18 ± 3.17 |
| Vertical VOR | 1.03 ± 2.33 | 1.03 ± 2.18 |
| VMS | 0.97 ± 2.35 | 1.18 ± 2.95 |

EQ2: Will there be differences in KD reaction time in youth athletes with a history of concussion?

To determine if there were differences on KD test performance between individuals with and without a history of concussion, individuals that reported a history of concussion were matched on sex, sport, and age with individuals without a history of concussion. An ANCOVA was then conducted, which revealed no significant difference ($F_{(1, 55)} = 2.65; p = .10; \text{partial } \eta^2 = .03$) between the 38 individuals with a history of concussion and 38 match controls without a history of concussion. Mean results showed individuals without a history of concussion

($M=48.88s$, $SD=10.46$) read slightly faster than individuals who reported a history of concussion ($M=52.11s$, $SD= 10.44$), although not significantly different from one another.

EQ3: Will there be differences in VOMS symptom provocation in youth athletes with a diagnosed learning disability?

To determine if athletes with a history of a learning disability, such as ADHD, ADD, or dyslexia, have differences in VOMS symptom provocation than individuals without a learning disorder, those individuals who reported as being diagnosed with a learning disability were matched on sex, sport, and age with individuals that were not diagnosed with a learning disability. A MANCOVA was conducted, which revealed no significant differences in symptoms provocation on all VOMS subscales of smooth pursuit ($F_{(1, 57)} = 1.67$; $p = .20$; partial $\eta^2 = .02$), horizontal saccades ($F_{(1, 57)} = 1.00$; $p = .31$; partial $\eta^2 = .01$), vertical saccades ($F_{(1, 57)} = 1.21$; $p = .27$; partial $\eta^2 = .02$), convergence ($F_{(1, 57)} = 1.13$; $p = .29$; partial $\eta^2 = .02$), horizontal VOR ($F_{(1, 57)} = .44$; $p = .50$; partial $\eta^2 = .00$), vertical VOR ($F_{(1, 57)} = .51$; $p = .47$; partial $\eta^2 = .00$), and VMS ($F_{(1, 57)} = .05$; $p = .81$; partial $\eta^2 = .00$). While not significant, individuals without a diagnosed learning disability reported lower symptom scores than individuals who were diagnosed with a learning disability.

An ANCOVA also was conducted to determine if differences occur on NPC distance. Results revealed no significant differences between individuals with and without a learning disability ($F_{(1, 57)} = 3.25$; $p = .07$; partial $\eta^2 = .05$), however the mean distance for individuals with a learning disability had over a 1cm difference ($M=2.67cm$, $SD=3.26$) in NPC distance than their match controls without a learning disability ($M= 1.38cm$, $SD=2.13$).

An ANCOVA also revealed that there were no significant differences between baseline symptom reporting and diagnosis of a learning disability ($F_{(1, 57)} = 1.36$; $p = .24$; partial $\eta^2 =$

.02). Individuals without a learning disability reported a lower symptom mean score ($M=0.10$, $SD=.40$) than individuals with a learning disability ($M=.30$, $SD=.83$), however these results are not significant.

EQ4: Will there be differences in KD reaction time in youth athletes with a diagnosed learning disability?

To determine if KD reaction time was different between individuals with and without a diagnosed learning disability, individuals with a learning disability were matched by sex, sport, and age to individuals with a learning disability. An ANCOVA was conducted, which revealed no significant difference on reading times ($F_{(1, 57)} = 1.90$; $p = .17$; partial $\eta^2 = .03$). While not significant, individuals without a diagnosed learning disability read the 3 test cards 3 seconds faster ($M=53.89s$, $SD=11.82$) than individuals with a diagnosed learning disability ($M=57.50s$, $SD=11.73$).

CHAPTER 5

DISCUSSION

The purpose of the current study was to investigate sex differences on the Vestibular/Ocular Motor Screening (VOMS) and King-Devick (KD) test among youth athletes. A secondary purpose of this study was to examine the relationship between KD test performance and ocular performance on the VOMS assessment. This study also served to provide normative data for youth athletes.

5.1 General Summary of Results

The results of the current study indicated that male and female youth athletes aged 8-14 years old do not differ on baseline symptom reporting, nor baseline symptom provocation on the VOMS assessment. Females, did however, differ from males on the KD ocular motor reading test. Specifically, females took significantly less time to perform the concussion assessment than males. Relationships between KD performance and ocular motor performance on the VOMS assessments of smooth pursuit, horizontal and vertical saccades, and convergence revealed no relationship.

Likewise, with regard to concussion history and learning disability, individuals who presented with a history of concussion or are diagnosed with a learning disability, do not differ from their match control counterparts on the VOMS and KD assessments. Additionally, no differences were discovered with baseline symptom reporting between the two groups and their match controls.

5.2 Vestibular Ocular Motor Assessment

This current study aimed to help provide normative values for the VOMS assessment in a youth population, along with baseline associations. The results of this study are similar to Kontos

and colleagues (2016) who reported a baseline range of 0.35-0.41 on VOMS subscales, with a small percentage (range= 6-11%) of athletes over the clinical cutoff scores. In this current study, VOMS subscale scores ranged from 0.49-0.70. Mucha et al. (2014) reported that no healthy controls reported a total symptom score over the 2-symptom clinical cutoff level, whereas almost 15% of youth athletes in the current study reported total symptom scores over the cutoff. These higher scores in youth athletes may be attributed to the ability to effectively understand and accurately rate their symptoms as compared to collegiate athletes. It has been theorized that younger children may not have the proper vocabulary or insight to describe symptoms (Ellis, Leddy, & Willer, 2014), or proper understanding of grading symptoms on a Likert scale. In this current study, between 10% and 13% of athletes baseline scores were over the clinical cutoff scores, which again may be attributed to the youth athlete's ability to understand and rate their symptoms accordingly. While the prevalence of vestibular disorders in the pediatric population extends upwards of 15%, it may be possible that this 10-13% false positive rate may be indicative of an underlying vestibular disorder, that could be recognized by the VOMS assessment (Gioacchini et al., 2014).

Near-point convergence (NPC) distance was also similar to Kontos and colleagues (2016) who reported a NPC average distance of 2.09cm, whereas this study had an average distance of 1.59cm. Kontos and colleagues also reported that 11% of participants in their sample had abnormal levels of NPC distance, with an average distance of 5cm or more. Similarly, the current study had roughly 11% of the sample over the clinical cutoff scores. Despite having 10.9% of youth athletes reporting abnormal NPC levels equal to or over the 5cm cutoff, these findings are similar with previous findings in a youth ice hockey cohort, which reported 11.5% of the sample with abnormal NPC (≥ 6 cm) (Vernau et al., 2015). These results are slightly higher than the

reported prevalence of 5% in healthy individuals, but fall in the normal reported range of 1%-33% (Scheiman et al., 2003). It is hypothesized that higher average NPC distances were observed due to younger participants having a harder time differentiating the exact point of convergence.

5.3 KD and Ocular Motor Assessment

This is one of the first studies to attempt to provide normative baseline reference values for male and female youth athletes aged 8-14 years old for the KD test, whereas previous normative reference values have only been published for high school football players (Alsalaheen et al., 2015) and professional male hockey players (Vartiainen et al. 2014). The normative reference values ($M=54.33s$, $SD\pm 11.54$) from this current study are consistent with King and colleagues (2015) who reported a completion time of 62.2 seconds for junior rugby league players aged 9-11 years old. As our sample had individuals as old as 14 years old, it could be assumed that the faster test times are due to the athlete over the age of 11 years. Normative reference values from this current study were slightly higher than averages reported by Munce and colleagues (2013) in 10 youth football players between the age of 12 and 14. These results are possibly higher due to a larger sample in this current study, along with including athletes as young as 8 years old.

The findings of the current study revealed that youth athletes between the ages of 12 and 14 years of age ($M=47.41$ seconds) demonstrated faster KD reading times than athletes between the ages of 8 to 11 years of age ($M= 57.04$). Improvements with age are consistent with previous findings that KD total reading time decreases with advancing age of youth athletes (Galletta et al., 2015). More specifically, Alsalaheen and colleagues (2015) reported that high school football players aged 16 to 18 had faster total times than those aged 13 to 15. This association with age

and improved KD times can be explained by developmental changes in both saccadic eye movement and cognition (Galletta et al. 2015). Eye movement tasks, such as saccades, require frontal lobe circuits that begin to reach stabilization around adolescence, along with other brain develop changes (Luna, Velanova, & Geiger, 2008). With increasing age, individuals also develop faster processing speeds (Iverson et al., 2003), which allow for a faster reading and completion time on the KD test (Galletta et al., 2015).

The overall results of KD test time per card and overall score are supported by previous pre-season findings by Munce et al. (2014) who reported an overall average time of 47.35 seconds with 14.63 seconds for test card 1, 15.30 seconds for test card 2, and 17.42 seconds for test card 3. The difference between trials was also supported as the current study noted a 1.64 second improvement on the second trial, which is consistent with improvement on the second trial as compared to the first trial. However, one possible explanation for the 1.6-second improvement in time duration between trials as compared to King and colleagues, 5.5-second improvement is the higher reliability in the current study.

The reliability analysis of the KD test revealed a good reliability between test trials (ICC= 0.94, 95% CI: 0.93-0.95). Overall, the reliability in this current study is comparable to reliability scores (ICC range: 0.89-0.95) previously reported in junior rugby players, high school football players, professional male ice hockey players, and mixed martial arts fighters (King et al., 2015; Alsalaheen et al., 2015; Vartiainen et al., 2014; Galletta et al., 2011). This current study also displayed good reliability between test cards, similar to previous results in professional male ice hockey players (Vartiainen et al., 2014).

5.4 Vestibular and Ocular Motor Relationship

This is the first study to have assessed the relationship of the KD assessment with ocular motor scores on the VOMS assessment. Overall, ocular motor scores had a very poor correlation with KD reading time. These results are different from previous associations of the KD test, with significant relationships with visual motor speed and reaction time (Vernau et al., 2015; Tjarks et al., 2013), along with lower SAC total scores (Benedict et al., 2015). One of the main possible explanations for the poor relationship between the KD and VOMS test is the difference in the measurements of each test. Despite both the KD and the ocular subscales of VOMS utilizing visual tracking, both smooth pursuit and saccadic eye movement, the VOMS test relies on subjective symptom provocation, where the KD test measures visual processing and reaction time based off of the visual tracking (Sussman, Ho, Pendharkar, & Ghajar, 2016). Previously well- correlated KD test relationships have utilized neurocognitive testing, measuring similar variables, not symptom provocation.

5.5 Sex Differences in Vestibular and Ocular Motor Assessment

This is one of the first studies to directly examine sex differences on the VOMS and KD assessments. More specifically, the first aim of the current study was to examine sex differences on baseline symptom reporting. The current study did not reveal sex differences in youth athletes which is consistent with Piland and colleagues (2010) who also reported that sex differences did not occur on baseline concussion assessment (Piland et al., 2010). However, this finding contradicts with previous studies that have reported higher symptom reporting by female athletes at baseline (Kontos et al., 2012; Brown et al., 2015; Covassin et al., 2006; Shehata et al., 2009), especially in the youth population (Brooks et al., 2015). Previous studies reporting sex differences at baseline have used validated symptom scores with a greater number of symptoms,

including the PCSS and SCAT2 symptom checklists. These checklist features 22 different symptoms, whereas the VOMS assessment consists of just four symptoms: headache, dizziness, nausea, and foginess. Iverson and Lange (2003) reported that the most common symptoms reported at baseline in a healthy population were fatigue, irritability, emotional disturbances, difficulty concentrating, and sleep disturbances, all which were not assessed in the current study. Respectively, Covassin and colleagues (2006) identified the symptoms of fatigue, sleeping more than normal, drowsiness, sensitivity to light, sensitivity to noise, difficulty concentrating, nervousness, feeling emotional, sadness, difficulty concentrating, and visual problems to be higher in females at baseline. Baseline symptom reporting of fatigue, drowsiness, and sleep disturbances may be attributed to overtraining, time of season or lack of sleep. Brown et al. (2015) also reported a higher likelihood of symptoms including vision/hearing problems, headache/migraine, difficulty concentrating, energy disturbance, sleep disturbances, and emotional disturbances at baseline. A revised factor structure for the PCSS revealed that females reported higher symptoms in cognitive-sensory (eg, sensitivity to light, difficulty concentrating), sleep disturbances, sadness, nervousness, and vestibular-somatic (eg, headache, dizziness) symptoms. Furthermore, symptoms of headache, nausea, and emotional disturbances may be attributed to a female athlete's menstrual cycle (Covassin et al., 2006), which may not have an impact due to the growth and maturation phases of female athletes in the current study. Schneider and colleagues (2010) reported that female athletes aged 15-17 appeared to be the age where symptoms are felt at times when concussions are not present and elevated baseline symptoms are common. Therefore, it may be plausible for younger athletes aged 8-14 to not present with higher baseline symptoms.

The current study also revealed that there were no significant differences on the VOMS assessment between male and female youth athletes. In fact, there were no observed sex differences on any of the VOMS subscales. These results are comparable to Mucha et al. (2014), who reported that sex was not a significant covariate on all VOMS subscales in the association with the likelihood of diagnosing concussions. While Mucha et al. (2014) did not directly measure sex differences on baseline control performance, the current study's results have different interpretations. These results are different from Kontos and colleagues (2016) who reported sex differences on VOMS baseline assessment, specifically that females were more likely to have a 1 or greater VOMS score over the clinical cutoff level. One possible explanation for the lack of sex differences on the VOMS assessment may be due to the sample size of the study, specifically with a 2:1 male to female ratio.

This study is believed to be the first study to directly examine sex differences on the KD test. Female youth athletes performed significantly faster than youth males on total test time, roughly 5.4 seconds faster. While no previous literature has examined sex differences on the KD test specifically, similar vision and ocular function research can constitute for these sex differences (Covassin et al., 2010; Halpern et al., 1997). Sex differences have been reported between male and female athletes on baseline neurocognitive performance, with females having faster processing speed and reaction times than males (Covassin et al., 2010; Halpern, 1997). Due to the nature of the KD test requiring the athlete to read the test cards as quickly as possible, faster visual processing, reaction time, and reading time by females, may explain the differences between sexes. Also, it may be possible that more females completed their baseline testing post-practice as compared to males. This may have caused females to produce faster scores, since exercise has been shown to improve KD test time from pre-practice to post-practice (Galetta et

al., 2011; Munce et al., 2014). In addition, cognitive development research has reported that females perform better than males on verbal tasks and have faster language development due to more accurate speech production and greater fluency (Burton, Henninger, & Hafetz, 2005; Weiss et al., 2003). Due to the nature of verbally reciting numbers on the KD trial cards, this may factor into the occurrence of sex differences.

5.6 Impact of Concussion History on Vestibular and Ocular Motor Performance

Youth athletes who have self-reported a diagnosed history of concussion did not report more baseline symptoms than match control individuals without a history of concussion as measured by the baseline symptom scoring on the VOMS assessment, measuring severity of headache, dizziness, nausea, and foginess. Further assessment of symptom provocation on the VOMS assessment also revealed that there were no significant differences on VOMS subscale symptom provocation between history of concussion groups; however, individuals who reported a history of concussion did have higher subscale scores than match controls without a history of concussion on all VOMS subscales. These results of a lack of difference in symptom reporting based off of a history of concussion are comparable to those by Kontos and colleagues (2016) who reported that a history of concussion was not an associated risk factor on the VOMS assessment. These results are also opposed to previous research (Piland et al., 2010) that reports higher symptom reporting at baseline in individuals with a history of concussion. One possible explanation for no difference in symptom reporting is due to the age of the athletes in this current sample. Individuals in previous literature assessing the effects of concussion history on symptoms at baseline have included high school and collegiate athletes. In addition, most research has incorporated longer symptom scales (e.g. 22-item symptom checklist) instead of the assessment of just four symptoms. Another possible explanation for a lack of differences on the

VOMS baseline symptom reporting and the VOMS assessment is the small sample size of this study, with only 38 athletes in the history of concussion group.

This is the one of the first studies to directly examine the effect of a history of concussion on KD performance in a youth athletes. Despite results yielding no significant difference between individuals with a history and their match controls, these results are similar to other research (Alsalaheen, York, & Diebold, 2015; Vartiainen et al. 2014) on athletes with a history of concussion. In addition, athletes with a history of concussion did not differ on processing speed and reaction time (Covassin et al., 2010), which given the wide array of samples from youth to professional athletes, it may stand to reason that individuals would not differ on KD performance based on a history of concussion. It can be speculated that the ocular motor system, specifically saccadic eye movement does not suffer from effects that may be suspected of previous concussions. Also, a majority (89.4%, n=34) of the individuals in this current study that had reported a history of concussion only suffered 1 previous concussion. Therefore, it can be hypothesized that youth athlete's on-going developing brains may not suffer the same effects as an adult's myelinated brain. It is not understood when these changes may begin to take place or if there is a specific number of concussions that may increase the likelihood of seeing differences in brain function. Therefore, more research is warranted to examine the effects that a history of concussion may have on baseline concussion assessment.

5.7 Impact of Learning Disability on Vestibular and Ocular Motor Performance

Youth athletes with a diagnosed learning disability or attention problem did not differ significantly from their match control counterparts on total baseline symptom reporting scores of headache, dizziness, nausea, and foginess. These results are conflicted with Nelson et al. (2016) who reported a higher symptom reporting in individuals with ADHD. However these symptoms

that were significantly different consisted of difficulty concentrating, fatigue, sleep disturbances, difficulty remembering, and balance problems, so the lack of differences in headache, dizziness, nausea, and foggiess may provide some similarity and validity to the current results.

Youth athletes with a diagnosed learning disability also did not differ from their match control counterparts through all VOMS subscales. One possible explanation for a lack of differences between youth athletes with a diagnosed learning disability is the low sample size, with only 30 athletes reporting with a learning disability. It may also be possible that differences did not occur on the VOMS subscales, since the scoring is based off of symptom provocation, which the four symptoms recorded were found to not impact symptom reporting in individuals with a learning disability (Nelson et al., 2016). This is believed to be the first study to directly examine VOMS and symptom provocation differences in individuals with a learning disability to attention problem.

Youth athletes with a diagnosed learning disability or attention problem did not perform significantly different from match controls who did not have a learning disability or attention problem on the KD test. Individual match controls without a learning disability or attention problem performed 4 seconds faster on the KD test than those with a learning disability or attention problem. This faster completion time for individuals with a learning disability or attention problem may be explained by previous research that noted slower visual motor speed and reaction times both at baseline (Elbin et al., 2015; Zuckerman et al., 2013) and post-concussion (Mautner et al. 2015) in individuals with a learning disability or attention problem.

Due to the modifying risk of learning disability and ADHD on concussion assessment, it may be beneficial producing normative data for specific groups of individuals that may suffer

from the modifying conditions on the VOMS and KD tests. Clinicians should also use caution when interpreting results of individuals with ADHD and learning disability.

5.8 Limitations

The current study was not without limitations. The ability of participants to accurately and honestly self-report symptoms of headache, dizziness, nausea, and foginess on the VOMS assessment is imperative as false or inaccurate responses may threaten validity and reliability of VOMS data. This is defined as the Hawthorne Effect; which is an alteration in behavior or performance resulting from the awareness of being involved in a research study (Campbell, Maxey, & Watson, 1995). In addition, the state of Michigan has undergone drastic increases in concussion awareness among athletes, parents, and coaches, which may increase the likelihood that underreported symptoms, as they know concussion-like symptoms mandates removal from play, and that intentionally performing more poorly than normal may avoid detection of a concussion. The ability of participants to put forth maximum effort on the KD test, is also threatened by the Hawthorne Effect. Selection bias did occur due to employing a convenient rather than random sample, with all participants recruited from the mid-Michigan area. Also, data were collected during multiple points of the year and in different settings (indoors, sideline, etc.). Data were also collected by multiple clinicians, testers, and research volunteers, which may threaten the test reliability of the assessments. Another limitation to this study, was that the participants completed one test after another, with roughly a 15-30 second break between assessments. This may have caused the participants to fatigue, during the testing. Lastly, some athletes completed their baseline testing at various points of practice, depending on practice schedules and availability (before, during, or after).

5.9 Future Directions

While the results of the current study were helpful in advancing the knowledge of influencing factors such as sex differences, history of concussion, and diagnosed learning disability on the VOMS assessment and the KD test in youth athletes, future research is still needed. Further investigation into the VOMS assessment is warranted, specifically normative values for all age groups and scholastic sport levels (high school, college, etc.). Additional research is needed on comparing baseline VOMS assessments with post-concussion assessments. Post-concussion VOMS assessment should also focus on sex differences and concussion history as influential factors of outcomes. Further investigation on whether VOMS can help predict recovery time is also warranted. VOMS assessment outcomes should also aim to measure change from baseline symptom provocation to better understand the true provocation differences that may fall outside of the VOMS cutoff scores, which may better aid in concussion assessment, diagnosis, and management.

Continued research on examining KD in all ages of athletes is necessary along with developing both normative baseline reference values along with baseline associations with other screening measures for sport-related concussion. Further research is also needed to determine the KD test's long-term reliability, specifically over clinically relevant intervals (1 day, 1 week, 1 month, 3 months, etc.) and the ability to predict recovery. Lastly, further research is needed to determine which multifaceted, combination of concussion assessment and screening tools provide the most clinically useful, non-overlapping information to help manage not only pediatric concussion, but sport-related concussion in general.

5.10 Conclusion

In conclusion, there were no sex differences between male and female youth athletes on baseline symptom reporting and the VOMS assessment; however, female youth athletes produced significantly faster times on the KD test than male youth athletes. Individuals with a history of concussion did not perform differently on symptom reporting, VOMS, or KD assessments as compared to match controls. Likewise, individuals with a diagnosed learning disability or attention problem did not differ on symptom reporting, VOMS, or KD assessments as compared to match controls. Without reliable baseline measurements, it is very difficult for clinicians to know if performance indicates suspected injury. With increasing implementation of concussion screening tools, such as the VOMS and KD tests, into concussion diagnosis and management protocols, it is imperative to understand how individuals perform at baseline, and any associations between sex, age, history of concussion, learning disability and other modifiers that may hinder or affect outcome measures. Further research is needed on the VOMS and KD tests, especially with regard to baseline and post-concussion assessment, as a brief screening tool. It is important to use best clinical practice and that the VOMS and KD tests should not be used alone as a screening tool, but may be beneficial to incorporate into a multifaceted evaluation approach to diagnosing and managing sport-related concussion.

APPENDICES

APPENDIX A
DEMOGRAPHIC SURVEY

NAME OF CHILD: _____

GENDER: ___Male ___Female

AGE: _____

HEIGHT: _____ feet _____ in. WEIGHT: _____ lbs.

SCHOOL/ORGANIZATION: _____

SPORT: _____

Please 'CIRCLE' yes or no for the following questions. If yes, please answer.

1. Has your child ever been diagnosed with a concussion? **Yes** **No**

 If YES, how many? _____

2. Has your child ever been diagnosed with headaches or migraines? **Yes** **No**

3. Does your child have a learning disability, dyslexia, ADHD/ADD or seizure disorder? **Yes** **No**

4. Has anyone in your family ever been diagnosed with any aforementioned problems? **Yes** **No**

 If YES, explain:

APPENDIX B

VOMS GRADING SHEET

EQUIPMENT NEEDED: PEN, TAPE MEASURE, PENCIL

Athlete Name: _____

Tester Name: _____

Date: _____

CHECK FOR CORRECTED VISION!

DOES ATHLETE WEAR GLASSES/CONTACTS Y N

ARE THEY WEARING THEM: Y N

| Vestibular/Ocular-Motor Test: | Not Tested | Headache 0 – 10 | Dizziness 0 – 10 | Nausea 0 – 10 | Fogginess 0 – 10 | Comments |
|--|-------------------|----------------------------|-----------------------------|--------------------------|-----------------------------|---|
| Baseline Symptoms | N/A | | | | | |
| Smooth Pursuits (H TEST) | | | | | | |
| Saccades – Horizontal (Goalpost test) | | | | | | |
| Saccades – Vertical | | | | | | |
| Convergence (Near Point) Tell me when you see two! | | | | | | (Near point in cm): Measure 1: _____ Measure 2: _____ Measure 3: _____ |
| VOR – Horizontal (Thumbs up!) | | | | | | |
| VOR – Vertical (Drive the car) | | | | | | |
| Visual Motion Sensitivity Test (Stand up and twist w/thumb out) | | | | | | |

APPENDIX C

INSTITUTIONAL REVIEW BOARD (IRB) APPROVAL FORM

**MICHIGAN STATE
UNIVERSITY**

July 21, 2015

To: Tracey Covassin
105 IM Sports Circle

Re: **IRB# 15-702** Category: **EXPEDITED 4**
Approval Date: July 17, 2015
Expiration Date: July 16, 2016

Title: Concussion Assessment in Youth Athletes

**Initial IRB
Application
Approval**

The Institutional Review Board has completed their review of your project. I am pleased to advise you that **your project has been approved.**

The committee has found that your research project is appropriate in design, protects the rights and welfare of human subjects, and meets the requirements of MSU's Federal Wide Assurance and the Federal Guidelines (45 CFR 46 and 21 CFR Part 50). The protection of human subjects in research is a partnership between the IRB and the investigators. We look forward to working with you as we both fulfill our responsibilities.

Renewals: IRB approval is valid until the expiration date listed above. If you are continuing your project, you must submit an *Application for Renewal* application at least one month before expiration. If the project is completed, please submit an *Application for Permanent Closure*.

Revisions: The IRB must review any changes in the project, prior to initiation of the change. Please submit an *Application for Revision* to have your changes reviewed. If changes are made at the time of renewal, please include an *Application for Revision* with the renewal application.

Problems: If issues should arise during the conduct of the research, such as unanticipated problems, adverse events, or any problem that may increase the risk to the human subjects, notify the IRB office promptly. Forms are available to report these issues.

Please use the IRB number listed above on any forms submitted which relate to this project, or on any correspondence with the IRB office.

Good luck in your research. If we can be of further assistance, please contact us at 517-355-2180 or via email at IRB@msu.edu. Thank you for your cooperation.



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Sincerely,

A handwritten signature in black ink, appearing to read "Ashir Kumar", enclosed in a rectangular box.

Ashir Kumar, M.D.
BIRB Chair

c: Ryan Moran

REFERENCES

REFERENCES

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