EXAMINING CONCURRENT VALIDITY, RELIABILITY, AND SEX AND AGE NORMATIVE VALUES OF THE IMPACT QUICK TEST-PEDIATRIC VERSION

By

Meghan E. LaFevor

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Kinesiology-Doctor of Philosophy

2017

PUBLIC ABSTRACT

EXAMINING CONCURRENT VALIDITY, RELIABILITY, AND SEX AND AGE NORMATIVE VALUES OF THE IMPACT QUICK TEST-PEDIATRIC VERSION

By

Meghan E. LaFevor

Purpose: The purpose of this study was to collect normative data, evaluate concurrent validity, and examine reliability for the ImPACT Pediatric and ImPACT Quick Test-Pediatric Version. This study also explored the factors of age and sex for performance differences. **Methods:** A total of 202 youth athletes, 6 to 11 years of age volunteered to participate in this study. All athletes completed both the ImPACT Pediatric and ImPACT QT-PV during a testing session. The assessments were administered back-to-back, alternately. For the reliability portion of the study, 38 youth were administered the same assessments in a second testing session 1 week following the first testing session. **Results:** The ImPACT QT-PV constructs were dissimilar to the ImPACT Pediatric constructs, deeming it an invalid youth concussion assessment in its current form. Neither assessment demonstrated acceptable test-retest reliability. Age was found to affect performance scores on the ImPACT Pediatric, however only one difference was found based on sex within the ImPACT Pediatric. **Conclusions:** Further examination and revision of the ImPACT QT-PV should be conducted before its release for public use. Additionally, the ImPACT Pediatric and ImPACT QT-PV should be investigated for factors leading to instability of measurement over time. Cognitive performance on ImPACT Pediatric revealed an association between increasing age and better performance, however males and females demonstrated little difference in performance scores overall.

ABSTRACT

EXAMINING CONCURRENT VALIDITY, RELIABILITY, AND SEX AND AGE NORMATIVE VALUES OF THE IMPACT QUICK TEST-PEDIATRIC VERSION

By

Meghan E. LaFevor

Purpose: The purpose of this study was to collect normative data, evaluate concurrent validity, and examine reliability for the ImPACT Pediatric and ImPACT Quick Test-Pediatric Version. This study also endeavored to explore the factors of age and sex for performance differences. **Methods:** A total of 202 youth athletes, 6 to 11 years of age, were recruited from Michigan, Tennessee, and Alabama for participation in this study. All athletes completed both the ImPACT Pediatric and ImPACT QT-PV in a counterbalanced fashion during a single testing session. For the reliability portion of the study, 38 youth completed a second testing session 1 week following the first testing session with the same assessments administered. A series of statistical analyses (e.g. correlation, ICC, ANOVA, ANCOVA) were conducted with a *p*-value set at 0.05. **Results:** The ImPACT QT-PV constructs did not correlate with the ImPACT Pediatric constructs ($r = -0.13 – 0.12$), deeming it an invalid youth concussion measure in its current form. Neither assessment demonstrated adequate test-retest reliability, with ICCs ranging from 0.11-0.75. Age was found to affect performance outcomes on the ImPACT Pediatric ($p = 0.00$), however only one difference was found based on sex ($p = 0.004$) within the ImPACT Pediatric. **Conclusions:** Further examination and revision of the ImPACT QT-PV should be conducted before its release for public use. Additionally, the ImPACT Pediatric and ImPACT QT-PV should be investigated for factors leading to instability of measurement over time. Cognitive performance on the ImPACT Pediatric revealed an association between increasing age and better performance, however males and females demonstrated little difference in performance outcomes overall.

This work is dedicated to my parents, Paul and Kim LaFevor, my fiancé, Joe Fox, and all those other special people who believed in me along the way. "Let us run with endurance the race that is set before us." -Hebrews 12:1

ACKNOWLEDGMENTS

I would like to first thank God, my heavenly father, for His direction and unending support throughout my life. Two verses that were indispensable reminders during the hard days of this feat were, Philippians 4:13, "I can do all things through Christ who strengthens me" and Romans 8:28, "We know that all things work together for the good of those who love God: those who are called according to His purpose." He has never failed me.

Next, I would like to extend my sincerest appreciation to my advisor, Dr. Tracey Covassin. Without your mentorship and support, I would not be where I am today. Just as the robin nurtures her offspring, helping them grow into strong, capable adults, so you too inspired and nurtured me. Although at times I was uncertain of my own capabilities, you knew when it was time to push me out of the nest so I could learn to fly. And what a beautiful and rewarding, but difficult, journey it has been. I could not be more grateful for this experience to study and be under the guidance of such a dynamic and devoted educator and scholar. From the bottom of my heart I thank you. I will work earnestly the rest of my career to make you proud and reaffirm your investment in me.

I would also like to thank the rest of my dissertation committee, Dr. Francisco Villarruel, Dr. Chris Kuenze, and Dr. Tom Mackowiak. The many hours you dedicated in supporting me both inside the classroom to expand my perspective and knowledge, and throughout this endeavor of scholarly research was invaluable. Your numerous suggestions and feedback provided, only bettered the course my project, my dissertation, as well as myself as a researcher. I will be a better scholar and educator because each of you offered leadership, a good measure of inspiration, and shared your disciplinary expertise so generously with me. I hope to demonstrate the same commitment to learning and genuine passion for students I encountered during my academic journey. I welcome the opportunity to "pay it forward" during my academic career.

I would also like to acknowledge the research assistants who aided me in data collection, as well as my colleagues who additionally supported me throughout our time together at MSU. Thank you for all that you did to help me be successful. As is generally true, nothing worth anything is achieved in a vacuum; rather it is the culmination of one's own efforts coupled with the hard work of many who often go unseen.

I would like to recognize my parents, Paul and Kim LaFevor, for their unending support throughout my life. You both provided me with all the tools, resources, and opportunities in life to be successful. I most assuredly would not be where I am today without the both of you. Thank you for all that you have done for me and continue to do. From the late night phone calls with dad, to mom giving guidance every step of the way, thank you for dedicating 26 years to me. I hope I can continue to make you proud of the woman I have become and am still becoming. I love you both.

Last, I would like to recognize my fiancé, Joe Fox, for his unconditional support throughout this entire, tedious process. You spent countless hours proof-reading sections of paper you didn't understand, going with me to collect data so I could work in the car, and staying up late with me so I didn't have to work alone. Perhaps most importantly, you never let me give up, even when I thought the challenges insurmountable. You will never understand how much your support during this arduous accomplishment meant to me. Thank you, Joe, for being my sidekick on this meaningful and significant personal endeavor. I look forward to our next journey together in life. I love you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Overview of the Problem

Concussions have become a familiar health condition among the general public, garnering attention in sports broadcasting and with the popular media. In the sporting arena sports-related concussions (SRC) have become a public health concern, with over 300,000 athletes afflicted each year in the United States (Langois, Rutland-Brown, & Wald, 2006). With mounting concerns for this condition, initiatives have been facilitated in order to help alleviate the rapidly growing SRC numbers and concerns. SRCs are known to be produced by biomechanical forces, stemming from a jolt, blow, or hit to the head or any part of the body that causes the brain to be violently unsettled within the skull (McCrory et al., 2013). However, this complex injury affecting the brain remains relatively poorly understood. Due to differences in injury mechanism and location, pre-injury attributes, and individual comorbidities, the clinical presentation of a concussive injury can vary greatly. Moreover, the many different symptom presentations and cognitive decrements that follow SRCs have made this injury difficult to detect and manage. Furthermore, the reliance on athletes to self-report their SRC symptoms often cause this injury to go un-detected resulting in the athlete not being removed from play (Seifert, 2013).

Instead of seeing a physical deformity, symptoms associated with SRCs manifest as neurological dysfunction. These symptoms commonly have a rapid onset and typically resolve on their own within 7-10 days (McCrory et al., 2013). However, it is recognized that the nature of symptoms experienced by individuals and the resolution of these symptoms is variable. An athlete can experience one or any combination of 22 signs and symptoms after sustaining a SRC.

Headache is the most common symptom reported by athletes following a SRC (Frommer et al., 2011). Additionally, only 10% of all SRCs occur with loss of consciousness. Such an event may also be accompanied by short-term neurological dysfunction (Coghlin, Myles, & Howitt, 2009). Sustaining a head injury is known to have detrimental effects on cognitive and neuropsychiatric function. A decline in memory and attention span are key signs of a SRC, with long-term effects being linked to diseases such as dementia pugilistica, pugilistic parkinsonism, and Alzheimer's (Dekosky, Ikonomovic, & Gandy, 2010).

SRCs can vary in their clinical presentation from individual to individual, affecting a broad-spectrum of function. Since no single assessment tool can be relied upon for accurate SRC recognition, the National Athletic Trainers' Association (NATA) position statement recommends the use of a combination of screening tools be administered at baseline and post-concussion (Broglio et al., 2014). Therefore, current evidence-based recommendations for the evaluation of SRC suggest that a multifactorial approach including a mental status check, postural stability assessment, and neurocognitive test may be most effective for diagnosis (McCrory et al., 2013). As a result, there has been the development of numerous assessment batteries for each of these areas in attempt to better identify the presence of SRC. Due to the nature of sports and number of SRCs, there has been a pressing need for more accurate tools to identify signs and symptoms of SRC in athletes. Implementation of several clinical assessment batteries for baseline testing in the preseason has occurred in attempt to detect SRC in athlete's post-head injury. However, this multifaceted implementation typically takes place at the high school, collegiate, and professional sports levels. One explanation for this is that most SRC assessments that are commonly used, such as the Post-Concussion Symptom Score (PCSS), Standardized Assessment of Concussion (SAC), Sport Concussion Assessment Tool (SCAT), Balance Error Scoring System (BESS), and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), have been developed for assessing athletes 13 years of age and older. This leaves a gaping absence regarding youth populations 5-12 years of age.

To date, assessments for evaluating SRC in youth populations are limited. The only youth SRC assessments currently available for evaluation include the Child-Sport Concussion Assessment Tool 3 (Child-SCAT3), Multimodal Assessment of Cognition and Symptoms for Children (MACS), CogSport for Kids, and Immediate Post-Concussion Assessment and Cognitive Testing Pediatric (ImPACT Pediatric). With the recommendation of assessment taking on a multifaceted approach and the NATA's position statement suggesting the use of multiple assessment tools for baseline and post-concussion evaluation, this presents an obvious insufficiency at the youth level. Additionally, the current youth SRC assessment tools available lack psychometric properties, making their dependability questionable. This elevates the need for additional SRC assessment tools in the youth population in order to provide more substantial and well-rounded evaluation of this condition. One newly developed assessment for children 6-11 years of age is the ImPACT Quick Test-Pediatric Version. This SRC assessment tool would be a valuable addition to the sparse youth assessments available. It is currently undergoing testing and analysis for its clinical merit.

1.2 Significance of the Problem

There is an associated risk of head or brain injury when engaging in sports, especially those requiring contact/collision. SRCs are an emerging and growing problem, specifically in the youth population. This injury presents a great concern for youth because their brains are still undergoing maturation and development, and an injury to the brain could have irreparable repercussions (Cantu, 2016). Youth have been found to possess a physiologic predisposition for incurring a concussive injury, manifested in their head-to-neck ratio, neck musculature, and cranial bones (Gourley & McLeod, 2010). In conjunction with a greater likelihood of SRC incurrence, youth have also been found to be slower to recover from the symptoms and neurological decrements compared to their older counterparts (Kerr et al., 2016b). In lieu of these problematic findings, there is a need for more focalized attention on youth evaluation and assessments in order to combat this epidemic plaguing this population.

While the evaluation methodology using a mental status check, postural stability assessment, and neurocognitive test batteries is universally accepted for high school, collegiate, and professional populations, there continues to be many questions about the generalizability of these standardized methods to pediatric populations and a lack of evaluation standards for youth. As previously discussed, with this group being in their formative years, there is a legitimate concern and need to better understand the neurocognitive effects of SRCs on youth populations. The extent to which diagnostic capability can be improved, may lead to greater sensitivity and specificity of assessments, impairment specific treatment, and individualized return-to-play criteria that aim to improve long-term neurocognitive function in youth athletes. A critical factor that should be taken into account is the validity of an assessment. If an athlete gives poor effort or misinterprets the instructions of an assessment, the baseline score is deemed invalid. Without verifying the validity of an athletes assessment score, sports medicine professionals are not ensured to accurately interpret the testing results, which puts the athlete at risk for premature return-to-play and subsequent health consequences. Therefore, the addition of more youth SRC assessment tools, that have been validated and extend the scope of youth evaluation, need to be created and assessed for their merit. One such youth SRC assessment tool newly developed and ready for appraisal is the ImPACT QT-PV.

As with any newly developed assessment tool, the psychometric properties need to be examined for their quality. Two properties specifically requiring evaluation are reliability and validity. Reliability is the extent to which a measure consistently measures a construct of interest, while the validity is the extent to which an assessment measures what it is intended to measure. Without both of these properties being established and reaching acceptable levels, an assessment cannot be considered a valuable and trusted source of information retrieval. Additionally, an assessment must undergo further investigation to determine if certain individual characteristics, such as age or sex, have an inherent effect on resultant scores.

Many studies evaluating SRC assessment tools have rendered differences in construct outcomes based on age and sex. It has been purported that age does play a role in SRC evaluation and management, with younger athletes performing worse than older athletes (Covassin, Elbin, Harris, Parker, & Kontos, 2012; Quatman-Yates et al., 2014). Also, researchers have found that performance improves as age increases, indicating an age-related effect (Sharma et al., 2014). Therefore, examination of performance differences amongst a younger age range of 5-12 years old should also be conducted to determine if a there is a causal effect. Another factor that must be taken into consideration is sex. Studies have shown that there are performance differences between males and females. In high school and collegiate populations, it has been revealed that males out-perform females on visual-spatial tasks, while females perform better than males on verbal memory and literacy tasks at baseline and post-concussion (Covassin et al., 2006; Covassin et al., 2012). However, youth assessments have not been evaluated for age- and sex-related differences in baseline performance. Therefore, tools such as the ImPACT Pediatric and ImPACT QT-PV should be examined to determine if there are age- and sex-related differences in youth populations. Establishment of age and sex normative values could assist in better assessing and evaluating concussed athletes' scores by comparing them to pre-established values for their age and sex. This can allow for a more individualized approach to assessment in the absence of an individual having a baseline for comparison.

With many youth programs not having a health care provider on staff or readily available at practices and games, youth organization administrators and parents have few options post-head injury for evaluation. Most parents, out of concern and lack of other options, will take their child to the emergency room for assessment and treatment, which can be both costly and time consuming, not to mention a lot of the time unnecessary. The establishment and validation of more youth concussion assessments could allow youth sport administrators and parents access to useful tools to aid in concussion diagnosis and screening. Youth programs could also potentially partner with companies such as ImPACT, and for a nominal yearly fee be given access to youth assessments for baseline and post-injury evaluation for a SRC. This could offer more safety for youth participating in sports by allowing for better concussion assessment post-injury, while also providing youth parents with more information for making further health care decisions.

1.3 Purpose of the Study

The primary focus of the study is to 1) collect and summarize normative data on the ImPACT Pediatric and Quick Test-Pediatric Version (ImPACT QT-PV), 2) determine the concurrent validity of the ImPACT Quick Test-Pediatric Version with the ImPACT Pediatric, and 3) establish the test-retest reliability of the ImPACT Pediatric and ImPACT QT-PV. The secondary focus of this study was to explore age- and sex-related differences in baseline neurocognitive function in youth athletes.

1.4 Hypotheses

H_1: There will be a correlation between the ImPACT QT-PV constructs and the ImPACT Pediatric constructs assessing memory and reaction time; $\mu_0=\mu_1$

H_2: There will be a correlation between the ImPACT QT-PV constructs and the ImPACT Pediatric constructs from assessment time 1 to assessment time 2; $\mu_0=\mu_1$

1.5 Exploratory Questions

1. Are there age differences (i.e., 6-8 years, 9-11 years) in cognitive performance in youth athletes?
2. Are there sex differences in cognitive performance in youth athletes?

1.6 Operational Definitions of Terms

1. CONCURRENT VALIDITY – Measure of the extent a particular test correlates to a similar, already validated test. Both tests must be given relatively close together timing-wise.
2. CONCUSSION – Complex pathophysiological process affecting the brain, induced by biomechanical forces resulting from a blow to the head, or other part of the body that resulted in an alteration in mental status and one or more of the following symptoms: headache, nausea, sensitivity to light, memory loss, dizziness, fogginess, confusion, tinnitus, sleep disturbances, blurred vision, or loss of consciousness (McCrory et al., 2013).
3. COUNTERBALANCED MEASURES – Measures administered in an alternating arrangement in order to ensure the results are not directly related to the order of measure administration. Simply illustrated, some participants would be administered the ImPACT

QT-PV first, then the ImPACT Pediatric, while others would be administered the ImPACT Pediatric, then the ImPACT QT-PV.

4. NORMATIVE DATA – Data collected from a large sample population, from which a baseline range for a measurement may be obtained and used for reference and comparison.
5. YOUTH ATHLETE – Defined as a person between the ages of 6-11 years, who participates in an organized sport.
6. IMPACT PEDIATRIC CONSTRUCTS- Components of the assessment, which assess cognitive functions including attentional processes, immediate memory, visuospatial skills, response speed, cognitive speed, impulse control, and nonverbal spatial span.
    a. Word List- The test administrator reads five words to the youth and records their responses.
    b. Design Rotation- The youth is to choose the design that is presented in the exact same orientation as the sample stimulus.
    c. Stop & Go- The youth is to select the word "Stop" or "Go" based on which color the traffic light lights up.
    d. Memory Touch- The youth is to watch a sequence of red circles light up, then correctly select the same red circles in the same order.
    e. Picture Match- The youth selects two blue squares which reveals a picture on each. If the pictures match each other then the squares remain revealed, if not they turn back blue. The object is to match all the pictures.
    f. Color Match- The youth is instructed to tap the screen when the word and color match and to not tap is the word and color are different.

7. IMPACT QT-PV CONSTRUCTS- Components of the assessment, which assess the cognitive functions of memory and reaction time.
    a. Symbol Match- The youth is instructed to tap the number that corresponds to the symbol presented.
    b. Three Letters- The youth is presented three letters to memorize and asked to recall them after completing a subsequent task.
    c. Number Counting- The youth is asked to count backwards from sixteen down to one as fast as they can tapping the numbers in order.
    d. Eyetracker- The youth is asked to follow a moving red circle with their finger around the screen and tap it as quickly as possible when it turns green.

1.7 Limitations

This study was limited by a few factors including: 1) the ages of participants were not evenly distributed with more participants falling in the older youth age range, 2) there were more male youth participants than female youth participants, 3) the majority of youth sport participants were involved in the sports of basketball and football, which does not give a well-rounded view of all sports, and 4) although most tests were done in a shaded area under a tent or inside, a few tests were done outside in direct sunlight which caused a glare on the iPads making the screen hard to see for participants.

CHAPTER 2

REVIEW OF LITERATURE

SRC is an injury that continues to receive attention from both the popular media and sports medicine community. Approximately 1.6 to 3.8 million sports and recreational traumatic brain injuries occur every year in the United States, with 300,000 of these being categorized as SRCs (Langois, Rutland-Brown, & Wald, 2006). According to McCrory et al. (2013) a concussion is "a complex pathophysiological process affecting the brain, induced by biomechanical forces" (p. 250). As athletic participation rates continue to rise in youth, high school and collegiate populations, the incidence of SRCs is also expected to continue to escalate. Recent management recommendations call for using a multi-faceted approach for managing SRCs that consists of a sideline mental status test, postural stability assessment, and neurocognitive test batteries (McCrory et al., 2003). However, a problem exists relating to youth SRC measures. Currently, only a limited number of validated youth assessments are available for practitioner and public use during SRC screening. With the growing numbers of youth athletes and awareness for SRCs, there is a need for more reliable and wholesome validated measures to be created. The following literature review presents research findings on nine sequential topic areas related to SRC. These include the following: 1) Epidemiology for Youth, High School, and Collegiate Athletic Populations, 2) Pathophysiology of Concussions, 3) Assessment and Evaluation of Sports-Related Concussion, 4) Concussion Return-to-Play, 5) Sex Differences in Concussion Risk, 6) Age Differences in Concussion Outcomes, and 7) Concussion Evaluation in Youth Athletes. Each topic area was explored based on previous research.

2.1 Epidemiology for Youth, High School, and Collegiate Athletic Populations

Injury is commonplace in both professional and recreational sports with an estimation that 7 million sports-related injuries occur in the United States each year (Tripp, Ebel-Lam, Stanish, Brewer, & Birchard, 2011). Due to high impact contact sports, it has been noted that between 2% and 10% of all athletes remain at-risk for sustaining a SRC (Ruchinskas, Francis, & Barth, 1997). The CDC estimates that there are between 1.6-3.8 million sport and recreational concussions reported annually in the United States (Langois, Rutland-Brown, & Wald, 2006). While occurrence rates vary by level of play, one study noted as many as 63,000 varsity athletes, the majority being football, incurred a SRC while either practicing or playing their sport (Powell & Barber-Foss, 1999). Incidence rates of SRCs have been suggested to be on the rise. However, others maintain that it is essential to understand that there has been a substantive increase in the volume of available sports programs, growing numbers of those who have historically participated in their respective sport each year, limitations of past SRC research, and differences in severity and outcomes based on level of play (McKeever & Schatz, 2003). Some researchers have even proposed that under-investigated neuroanatomical differences are responsible for differences in SRC incidence rates across populations (Barnes et al., 1998).

Frommer, Gurka, Cross, Ingersoll, Comstock, and Saliba (2011) assessed these types of differences among athletic populations in their SRC research. They concluded that while 7.3 million high school athletes participate in organized interscholastic athletics in the United States each year, an alarming number of athletes experience SRCs during practice or competition. While Frommer et al. (2011) estimated that high school athletes represent 21% of the total reported SRCs each year, others have suggested a more modest impact of 8.9% (Gessel, Fields, Collins, & Comstock, 2007). The NCAA purports that SRCs represent 5 to 18% of collegiate injuries. While any athlete is at risk, most SRCs are found in largely contact sports such as football, soccer, ice hockey, and wrestling (Zuckerman et al., 2015), including in pediatric populations (McGuire & McCambridge, 2011).

The epidemiology of SRCs at a high school and collegiate level was assessed in a study by Gessel et al. (2007). A total of 8,293 injuries were reported in the sample group, which included 482 or 5.8% of all injuries resulting in a SRC. In all sports evaluated, with the exception of baseball and softball, SRC rates were universally higher in collegiate populations. It is unclear at this time why this may be the case, however it is known that athletes face far superior competition in the college setting, as well as generally have greater access to medical staff which could lead to increased SRC diagnosis. As a general observation, SRC rates have risen over the years in almost all sports at both the high school and collegiate levels (Table 1). There are many speculations for this emerging array, such as an increased number of athletes participating in sports, greater SRC awareness, and athletes being bigger, stronger, and more skilled. However, no reason put forth has yet been proven to be the specific cause. Further investigation is needed to determine the root of these patterns.

Table 1. *Reported Concussion Rates by Sport, Sex, and Competition Level (Rates per 10,000 athletic exposures)*

	High School				**College**			
Sport	**Lincoln (1997-2008)**	**Gessel (2005-2006)**	**Marar (2008-2010)**	**Datalyst Center (2010-2012)**	**Hootman (1988-2004)**	**Gessel (2005-2006)**	**Agel & Harvey (2000-2007)**	**Zucker-man (2009-2014)**
Football	6.0	4.7	6.4	11.2	3.7	6.1	-	6.7
Ice Hockey (W)	-	-	-	-	9.1[1]	-	8.2	7.5
Ice Hockey (M)	-	-	5.4		4.1	-	7.2	7.9
Lacrosse (W)	2.0	-	3.5	5.2	2.5	-	-	5.2
Lacrosse (M)	3.0	-	4.0	6.9	2.6	-	-	3.2
Soccer (W)	3.5	3.6	3.4	6.7	4.1	6.3	-	6.3
Soccer (M)	1.7	2.2	1.9	4.2	2.8	4.9	-	3.4
Wrestling	1.7	1.8	2.2	6.2	2.5	4.2	-	10.9

Table 1 (cont'd)

Field Hockey	1.0	-	2.2	4.2	1.8	-	-	4.0
Basketball (W)	1.6	2.1	2.1	5.6	2.2	4.3	-	6.0
Basketball (M)	1.0	0.7	1.6	2.8	1.6	2.7	-	3.9
Softball	1.1	0.7	1.6	1.6	1.4	1.9	-	3.3
Baseball	0.6	0.5	0.5	1.2	0.7	0.9	-	0.9
Volleyball	-	0.5	0.6	2.4	0.9	1.8	-	3.6

Hootman et al. (2007) data represent 16 years (1988-2004), except women's ice hockey, for which data collection began in 2000. SOURCES: Agel and Harvey, 2010; Gessel et al. 2007; Hootman et al., 2007; Lincoln et al., 2011; Marar et al., 2012; Datalys 2013; Zuckerman et al. 2015.

It has been noted that the most common mechanisms leading to a SRC include a fall to the ground, being hit by an object, or direct impact to the head from collision with another player (Seifert, 2013). The risk of sustaining a SRC for high school athletes has demonstrated a pattern based on certain risk factors by sport. The greatest volume of SRCs were found with high school football players that occurred while making running plays and making contact with another player. In high school soccer regardless of sex, heading the ball was the primary cause of SRC. In the predominantly male sport of wrestling, takedowns were found responsible for almost half (42.6 %) of SRCs (Gessel et al., 2007). McClincy, Lovell, Pardini, Collins, and Spore (2006) found that at the high school level 62,000 football-related concussions were sustained annually. While at the collegiate level in the entirety of football players, 34% were found to have experienced a single SRC and 20% multiple SRCs. With these high incidence rates, there remains a lack of research that clearly defines recovery mechanisms and physiology (McClincy et al., 2006).

When investigating SRC injury occurrence, it is important that certain entities such as policy makers, athletic directors, coaches, and parents be able to appropriately assess sports and their risk to athletes. Although scientifically a common reporting method is through athlete-based incidence rates, it has been argued that this is possibly not the most comprehendible form to the everyday layperson. Kerr et al. (2016a) investigated four measures of SRC incidence for their merit in a longitudinal study spanning 5 academic years. The measures evaluated included athlete-based rate, athlete-based risk, team-based rate, and team-based risk. Upon comparing these measures across 13 sports, it was found that they produced varying results in terms of incidence. Men's wrestling was found to display the highest athlete-based rate and risk, while men's football was discovered to boast the greatest team-based rate and risk. Team-based measures account for larger team sizes, which place more athletes at risk for SRC occurrence, such as in football. This contrasts athlete-based measures, which consider the athlete's personal risk divided by their team size. This automatically boosts smaller teams incidence rate and risk due to teams being small and injury occurrence high such as in the sport of wrestling. Although the rank order of these high contact sports were merely re-arranged based on which incidence measure was used, the authors purport that the team-based measures may be more intuitive for key stakeholders understanding (Kerr et al., 2016a).

Approximately 45 million youth (7-14 yrs) participate in sports in the United States, and each year 250,000 will visit the Emergency Department with a SRC (Bakhos, 2010). Epidemiological trends for SRC in youth sport are on the rise as emergency department visits for youth have doubled between 1997 and 2007 (Bakhos, 2010). Researchers have suggested that injury rates for SRC in youth football players (8-12 yrs) were comparable to high school and college populations (Kontos et al., 2013). Recently, researchers reported SRCs comprise approximately 9.6% of all youth football (5-14 yrs) athletic injuries (Dompier et al., 2015).

Through targeted studies, organized sports were found to increase the chances of concussive injuries by 6 times when compared to recreational activities by children (Gourley & McLeod, 2010). While any athlete is at risk for a SRC, most youth SRCs occur in contact sports such as football, soccer, ice hockey, and basketball (Sander, 2010), including in pediatric populations (McQuire & McCambridge, 2011). Each year in the United States there are approximately 23,000 football-related non-fatal type traumatic brain injuries (TBIs), with about 90% of these injuries acquired by youth between the ages of 5 to 18 years old. These data are likely an underestimation of the incidence of SRC in youth sport as the majority of youth leagues lack sufficient and consistent medical oversight. In older athlete age groups (i.e. 14-18 yrs) with appropriate and consistent medical coverage, as many as 40% of all SRCs go unreported (McCrea et al., 2004; Register-Mihalik et al., 2013). Moreover, relying on the athlete's self-report and disclosure of concussion symptoms is a subjective process that is often undermined by athletes minimizing and underreporting their symptoms (McCrea et al., 2004; Dziemianowicz et al., 2012). Utilizing more objective methods to assess a potential SRC is crucial to improving our ability to detect and properly manage concussed youth athletes.

SRCs in youth athletes are of greater concern due to their critical stage of brain development and propensity towards injury (McKeever & Schatz, 2013). It has also been proposed that their greater head-to-body ratio, weak neck musculature, and undeveloped cranial bones all make younger athletes more susceptible to a SRC (Gourley & McLeod, 2010). Seifert (2013) reported that through age 8 children generally have a disproportionate head-to-body size ratio and corresponding weak neck musculature. Also noted was that the release of excitatory neurotransmitters following trauma is more sensitive in the immature brain (Seifert, 2013). The pathophysiology of SRC in youth athletes will be discussed in the next section.

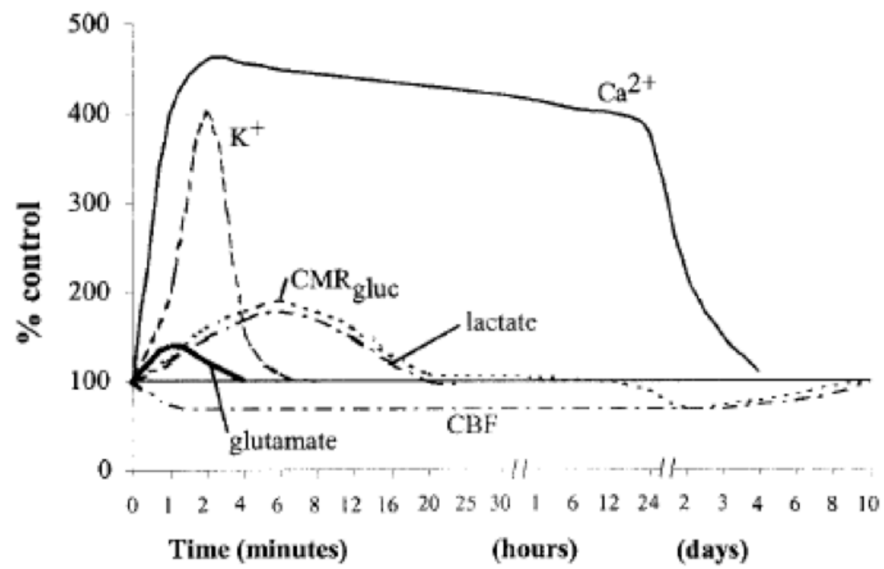
2.2 Pathophysiology of Concussion

From a historical perspective, ancient medical writings, like those of Hippocrates which date back to 400 B.C., define the conceptual term of concussion, although the term itself was not used until the 17th century by Marchetti (Snedden, 2013). However, from that time to modern day, there have been a myriad of descriptions that continue to expand and assert the varying nature of concussions. None had been universally adopted until the third International Concussion on Sport Conference in 2008, which included aspects of SRC such as brain dysfunction that presents as symptoms, physical signs, behavioral changes, cognitive impairments, and/or sleep disturbances (Snedden, 2013). The cause of a SRC is thought to be unknown to many people. Typically, a person thinks of a blow to the head as the cause of a SRC. Although this may be true, a blow to anywhere on the body, as long as an impulse is sent up to the brain, may be the cause.

As noted by Edwards and Bodle (2014), the pathophysiology of a SRC is complex. Cellular damage in caused by the forces of rapid acceleration and deceleration of the moving brain. Impact causes a chain of events inside the skull. The brain lags behind the movement of the skull and then rebounds toward the direction of impact. This causes the brain to impact the inside of the skull, followed by it settling back into its resting position. With any rotational movement of the head during time of impact, shearing forces and distortion of vascular and neural elements are increased (Edwards & Bodle, 2014).

There is research evidence that has previously presented these pathophysiological outcomes at a gross and cellular level. Pellman, Viano, Tucker, Casson, and Waeckerle (2003) demonstrated in their study using the National Football League (NFL) computerized photo analysis that on a gross anatomical level, the highest levels of strain forces are in the deep midbrain, mesencephalon, corpus callosum, and fornix. Giva and Hovda (2001) identified in their research the pathogenesis of axonal dysfunction on a cellular level and cited its complexity. They determined that there was a cascade of effects starting with the abrupt neuronal depolarization, leading to the release of excitatory neurotransmitters, ionic shifts, inactivation of sodium and potassium pumps, impairment in glucose metabolism, and dissociation of metabolism and cerebral blood flow. These alterations on a cellular level cause dysfunction to an individual and leave them impaired to a certain extent. Giza and Hovda (2001) have described these events as the “neurometabolic cascade” of concussion (Figure 1).

Figure 1. *The Neurometabolic Cascade Following Experimental Concussion*



K^+, potassium; Ca^{2+}, calcium; CMRgluc, oxidative glucose metabolism; CBF, cerebral blood flow. From “The Neurometabolic Cascade of Concussion,” by C. Giza and D. Hovda, 2001, *Journal of Athletic Training, 36,* p. 229. Reprinted with permission.

In a study by Dambinova, Shikuev, Weissman, and Mullins (2013), ∝-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid receptor (AMPAR) peptide assay in healthy nonathletes and concussed athletes was assessed to determine if it could serve as a brain-specific biomarker to differentiate the concussed subjects from the controls. All subjects had a single blood draw and were ImPACT tested, as well as the concussed athletes selected were given a magnetic resonance imaging (MRI) and neurocognitive consultation. The results indicated a statistically significant increase in AMPAR peptide in concussed subjects. This research revealed an increase in AMPAR was corroborated by a decrease in visual memory scores or reduced cognitive efficiency index by these individuals. In this pilot study their findings were positive for identification of impairment from the AMPAR peptide, however more research in this area is needed (Dambinova et al., 2013).

Similarly, in a study by Henry, Tremblay, Boulanger, Ellemberg, and Lassonde (2010), neurometabolic changes were discovered in concussed athletes within a week following their SRC. Concussed athletes and their matched controls underwent neuropsychological testing, as well as neuroimaging. Results from the neuropsychological test battery assessing verbal memory, visual memory, information processing speed, and reaction time revealed no group differences. However, the concussed athletes reported a higher number of symptoms with greater symptom severities than their matched controls. This was the only distinguishable clinical difference detected between the groups. However, neuroimaging via magnetic resonance spectroscopy found significant differences between concussed and control athletes in cortical areas of the brain. Concussed athletes displayed lower levels of N-acetylaspartate (NAA), a marker of neural integrity. This was observed in both the primary motor cortex (M1) and the dorsolateral prefrontal cortex (DLPFC). Also, decreased levels of glutamate (GLU), the principal excitatory neurotransmitter, were seen in the M1 of concussed athletes, but this finding was not reciprocated in the DLPFC. This suggests that although neuropsychological assessment scores may return to baseline values within a week, the brain may still be injured as evidenced by the depressed levels of NAA and GLU in the M1. The researchers also performed correlation analysis between symptom scores and metabolite changes. A significant negative correlation was found between self-reported symptom scores and NAA in the M1. Similarly, there was a significant negative correlation between symptom severity and GLU in the M1. These findings were particularly remarkable as they present a more objective means by which concussive symptoms can be determined and validated. This measure removes the guesswork when it comes to malingering athletes who continue to report symptoms after their resolution, as well as identifies those athletes who deny having symptoms that are present in order to return to play more quickly (Henry et al., 2010).

2.3 Assessment and Evaluation of Sports-Related Concussion

2.3.1 Symptoms

After a SRC occurs, it is usually followed by the presentation of one or more symptoms. Due to differences in injury mechanism and location, pre-injury makeup, and individual comorbidities, the clinical presentation of the injury can vary greatly (Seifert, 2013). Seifert (2013) suggests there are physical, cognitive, and emotional complaints, as well as sleep disturbances presented as signs and symptoms of a SRC. The most common symptom of a SRC is a headache, which is usually the first reported and last to resolve (Seifert, 2013). The results of a study by Gessel et al. (2007) evaluating symptoms in high school athletes also found the same findings. Symptoms can also include sensitivity to light or noise, sluggishness, confusion, depression, visual changes, dizziness, nausea, memory problems, and poor concentration. Signs that may be observed include the athlete's appearance of being dazed or confused, difficulty with instructions, mood or behavior changes, clumsiness, retrograde amnesia, or loss of consciousness (McGuire & McCambridge, 2011).

In general, clinical symptoms of SRC resolve prior to cognitive symptoms (Rosenbaum & Arnett, 2010). Cognitive symptoms include diminished attention and concentration, delayed information processing, and memory deficits (Rosenbaum & Arnett, 2010). Edwards and Bodle (2014) compiled a review on the causes and consequences of a SRC by stage of symptom onset. The presented symptoms in the aftermath of a SRC were found to vary from individual to individual and be composed of one or a combination of symptoms. They also indicated symptoms can present early, within minutes to hours of head trauma, or late, occurring days to weeks after the traumatic event. Early symptoms can include, vacant stare, delayed verbal and motor responses, confusion or inability to focus attention, slurred or incoherent speech, gross incoordination, emotions out of proportion to the situation, memory deficits, repeating questions, nausea, vomiting, dizziness, vertigo, and sometimes loss of consciousness. Later symptoms may include persistent headache, sleep disturbance, hypersomnia, poor attention and concentration, difficulty with memory, irritability, personality changes, and depression. Typically there is a resolution of symptoms within 7-14 days of SRC, however symptoms can last weeks, months, or even a lifetime (Edwards & Bodle, 2014).

According to Lear and Hoang (2012), other than the typical symptoms associated with a SRC, there are certain symptoms that warrant immediate attention by a medical professional. These "red flag" symptoms usually alert one to a more serious underlying problem beyond that seen with a common SRC. Included in this category would be focal neurological complaints, vomiting or headache that worsens after a period of improvement, or disorientation that has worsened since the injury occurred. Imaging techniques would not be recommended in the case of a SRC due to the fact that they would lack any substantive findings (Lear & Hoang, 2012).

Symptoms of a SRC have been determined to vary in all aspects from one individual to another. Symptoms can differ in their number, appearance, severity, resolution time, and progression into greater conditions overtime. These topics have received much attention in older populations, composed of high school and collegiate athletes, however researchers have since desired to evaluate SRC symptoms specifically at the youth level. A starting place in this analysis is factors that may impact symptom development. Dillard et al. (2016) evaluated factors that may influence post-concussive symptoms in 157 youth at a pediatric outpatient clinic. Of interest, group differences were examined to see if they contributed to varying total symptom scores measured by the PCSS. It was found that scores differed significantly on the basis of sex and injury type, with females and non-sports related injuries recording higher symptom scores. A history of psychiatric illness/disorder also approached significance with regard to PCSS scores. Factors that did not prove to have a significant impact on PCSS scores included reported loss of consciousness, race/ethnicity, or age. Sex, injury type, and psychiatric history factors, when placed into a regression model, were found to explain 23% of the variance in symptom scores. For endorsement of symptoms, youth females on average reported more symptoms than youth males. Females endorsed almost all symptoms on the PCSS at a higher rate, while males were found to more often report no symptoms. Injury type did not affect the number of symptoms endorsed. However, sports related injured youth were less likely to reported the symptoms of irritability, difficultly remembering, sleeping less than usual, trouble falling asleep, and sadness compared to those with a non-sports related injury. Also, youth with a sports-related injury more frequently reported experiencing no post-concussion symptoms than other injury types. This may be representative of how youth athletes may be misleading about their injury and underreport symptoms in order to continue to play (Dillard et al., 2016).

SRC recovery time can vary in length, with symptoms lasting anywhere from a few days up to several years in select individuals. In a study by Crowe et al. (2016) symptom recovery from SRC was tracked in youth athletes 10-17 years old. Symptom resolution and recovery were measured using the CogSport for Kids computerized neurocognitive SRC assessment, which was given as a baseline, as well as at days 5, 10, and 30 following the injury occurrence. It was found that by day 30 post-concussion, most participants resumed normal executive function. Also, the number and severity of symptoms decreased at each time point that participants were retested. From the data gathered using the CogSport for Kids assessment, there were interesting findings with regards to individual differences. When assessed as a group, cognitive problems were ascertained to have almost entirely resolved by day 30, with few differences found compared to baseline. However, when evaluated on an individual level, variability was identified with recovery trajectories when each participant's assessment scores were compared internally. When comparing assessment component scores for days 10 and 30, it was discovered that a few participants actually performed worse, rather than better as would be expected with recovery. Performance in most participants was found to improve over the reassessment time points, signaling an improvement in cognitive function. Therefore, with some participants not following this pattern, it is important for clinical practitioners to assess youth SRCs on an individual basis to ensure accurate determination of recovery status (Crowe et al., 2016).

With variance in SRC symptom recovery being a notable issue, some researchers have ventured to determine what factors and characteristics may contribute to this phenomenon. In a recent study, Grubenhoff et al. (2016) evaluated psychological factors potentially responsible for prolonged recovery from SRC symptomatology in children age 8-18 years. They found abnormal somatization scores in children with delayed symptom recovery compared to those with early symptom recovery. Also of note, and trending toward significance, state anxiety and psychological discomfort were more prevalent in children with delayed symptom recovery. However, when age, sex, and mechanism of injury (sport or non-sport) were adjusted, results were not found to be appreciably altered (Grubenhoff et al., 2016).

Extending these assertions and adding to them, prolonged recovery characteristics and symptoms in youth 5-18 years of age were explored in a study by Corwin et al. (2014). In their population sample, they determined that the median time post-concussion for the youth to return to school full time was 35 days, become completely symptom free took 64 days, and be cleared for full sport participation took 76 days. In regard to pre-existing conditions, it was found that youth who had anxiety or depression took twice as long to be fully cleared for participation than those without these conditions. In the initial presentation of symptoms, 66% of participants reported dizziness. It was found that those who experienced dizziness took 2.6 times longer for symptom recovery than those in which dizziness did not occur. Oculomotor examination exacerbated symptoms in 74% of the sample, with 62% demonstrating abnormal near point convergence. Those who experienced provocation of symptoms following oculomotor examination were more likely to be prescribed school accommodations, report a decline in grades at school, and require more time to return to school full-time, as well as experience a prolongation of symptoms greater than 4 weeks, take longer to become symptom free, and require a lengthier time to be fully cleared. Age was also found to play a role in recovery. Youth 12 years of age and younger were found to take the longest amount of time to become symptom free, taking almost twice as long as other age groups. Also, 13-16 year olds were found to take the greatest amount of time to return to school full-time. History of previous SRC was also found to affect recovery timeliness. Participants who had experienced 2 or more previous SRCs took over twice as long for symptom resolution, and those who experienced 3 or more were found to take 3.6 times as long for symptom resolution. In this study, 100% of participants with a history of 3 or more previous SRCs were prescribed school accommodations (Corwin et al., 2014).

A point of contention among researchers surrounding recovery is the effect computerized cognitive SRC testing has on concussed individuals. It has been debated whether computerized cognitive testing places too much stress on the already injured brain of concussed athletes. With cognitive rest being a recommendation following SRC, this leaves the question of whether cognitive testing following SRC could in fact prolong symptoms and subsequently, recovery. In a study by Brooks et al. (2016), the question of to test or rest following mTBI was explored in youth presenting to the Emergency Department to determine the effects on recovery. Participants included 154 youth 8-17 years old, half of which were tested with a computerized cognitive test, while the other half were not tested following their mTBI. The two groups did not differ significantly on any demographic or injury factors. Post-Concussion Symptom Inventory (PCSI) scores were recorded by both participants and their parents for a more well-rounded subjective report. PCSI were taken at baseline, 7-10 days, 1 month, 2 months, and 3 months to track recovery over time. There was found to be no difference in PCSI scores for those who underwent cognitive testing versus those who did not at all time points reported by both youth participants and their parents. There was also found to be no significant group difference in PCSI scores based on the length of the computerized cognitive test, being either full-length with 7-subtests taking approximately 28 minutes, or shortened-length with 4 subtests taking approximately 16 minutes to complete. Symptom recovery on an individual basis was also considered and measured to determine if the groups differed in symptom recovery. At each time point there was found to be no significant difference in terms of symptom recovery and the factor of cognitive testing. The findings of this study suggest that symptom severity and recovery are not affected by a youth's mental exertion on a computerized cognitive test post-mTBI. This also suggests that computerized cognitive assessments should be used post-concussion to aid in diagnosis and management of an injury (Brooks et al., 2016).

2.3.2 Post-Concussion Syndrome in Youth

Post-concussion syndrome (PCS) is a diagnosis becoming more prevalent in youth populations. PCS is defined per International Classification of Diseases, 10th edition as presenting with a minimum of 3 concussion symptoms at least one month post-injury (Ellis et al., 2015b). It has been suggested that youth recover at a slower pace than older populations, however, some researchers have desired to better understand the condition of PCS and its development. Ellis et al. (2015b) conducted a study evaluating the prevalence, clinical features, and risk factors of psychiatric outcomes in children who suffered a SRC. Results indicated that a prior history of SRC or multiple SRCs might play a significant role in the development of psychiatric outcomes. Of the participants who developed psychiatric outcomes post-injury, 75% reported 1 or 2 previous SRCs and 25% reported 3 or more previous SRCs. Also associated with the development of psychiatric outcomes, were higher initial ratings of PCSS and emotional PCSS. This was particularly noticeable in participants who reported feeling nervous, sad, or more emotional at the time of presentation. Retrospectively, it was realized that 90% of participants who developed psychiatric outcomes post-injury, met the criteria for post-concussion syndrome (PCS) at diagnosis. This signifies the need for practitioners to assess those who may qualify as having PCS for psychological changes or disorder development (Ellis et al., 2015b).

Similar findings were reported in a study by Morgan et al. (2015) where factors leading to PCS development in youth athletes 9-18 years old were evaluated. It was found that an increasing number of previous concussions, personal history or family history of psychiatric illness or mood disorders, family history of migraines, and delayed concussion symptoms onset, were each predictive in the development of PCS. Likewise, race, sex, loss of consciousness, amnesia, pain reliever medications, patient migraines, ADHD or a learning disability, and wearing a helmet at the time of injury, were not identified as related to PCS onset. Some of these findings contradict those of previous studies, however the sample from this study was composed of solely SRCs in youth athletes, as opposed to a variety of mechanisms included in most studies of this nature. Of particular interest was the finding of delayed symptom onset as a predictor of PCS. Delayed symptom onset was defined as symptoms that did not appear until more than 3 hours after the injurious event. The researchers propose that this factor may be indicative of PCS due to the fact that these athletes are typically not removed from play because they are asymptomatic. Therefore, these athletes are allowed to continue to play, equally incurring more damage to their already injured brain, and further increasing the injury severity. This finding provides additional encouragement to practitioners for evaluating possible concussive head injuries by multifaceted means, and not relying exclusively on the self-reported symptoms endorsed by athletes (Morgan et al., 2015).

Interesting additional findings were found in another study identifying confounding factors leading to the development of post-concussion syndrome (PCS). In a sample of 101 participants with a mean age of 14.2 years, 77 were diagnosed with acute SRC, while the remaining 24 were assessed as having PCS at initial evaluation. With particular attention to the PCS group, it was determined that certain factors increased a youths' risk of PCS development. These included amnesia at time of SRC, increase in PCSS scores, and meeting the criteria for vestibular-ocular dysfunction (VOD). Of these factors, VOD specifically should be noted as it has only recently been studied for its merit. VOD was diagnosed in 63% of those with PCS, and was also found to lead to a greater duration of SRC symptoms. Even more, while controlling for the confounding effects of PCSS and migraine history, those youth who were diagnosed with acute SRC as well as VOD at initial assessment, were 4 times as likely to develop PCS later on. With VOD proving to be a substantial finding in PCS development, practitioners should take note and evaluate for VOD in athletes with SRC (Ellis et al., 2015a).

2.3.3 Evaluation of Self-Reported Symptoms

The many different symptom presentations and cognitive decrements that follow SRCs have made this injury difficult to detect and manage. Furthermore, the reliance on athletes to self-report their SRC symptoms often cause this injury to go un-detected as they purposely avoid being removed from play (Seifert, 2013). Self-report symptoms are a common means of SRC assessment by 85% of athletic trainers, with symptom evaluation used by 80% of sports medicine professionals in making return-to-play decisions (McLeod & Leach, 2012). Approximately 15% of athletic trainers report that assessment of symptoms is the primary decision making tool as it is readily available and inexpensive to administer (McLeod & Leach, 2012). While sports medicine professionals rely heavily on symptom reporting by concussed athletes, studies have concluded that many concussed athletes did not indicate differences in symptoms, although they demonstrated neurocognitive impairment in reaction time and verbal memory. It is suggested through this research that there are two possible explanations: 1) athletes are not fully aware of the extent to which they are experiencing symptoms, and 2) athletes will minimize their stated symptoms (Covassin et al., 2008). Therefore, there are lingering concerns in the utilization of these scales as a primary means of evaluation. This is due to the fact that many of these scales have not been validated before their use in clinical practice, yet are being used in making important return-to-play decisions (McLeod & Leach, 2012). Also, Piland, Ferrara, Macciocchi, Broglio, and Gould (2010) note that current self-reported symptoms research lacks psychometric and measurement evidence as well as instrument standardization.

Valovich, McLeod and Leach (2012) examined which self-report symptoms scales or checklists were the most psychometrically sound for clinical use in assessing SRCs. Drawing from a pool of 421 related articles, these researchers concluded that while as many as 20 scales were utilized, they focused their analysis on 6 primary scales which included: 1) Pittsburgh Steelers Post-Concussion Scale (17 items), Post-Concussion Symptom Assessment Questionnaire (10 items), Concussion Resolution Index post-concussion questionnaire (15 items), Signs and Symptoms Checklist (34 items), SCAT post-concussion symptom scale (25 items), and Concussion Symptom Inventory (12 items). These assessment methods consistently evaluated symptoms of a SRC, but the number of items assessed varied significantly between scales. While most scales used a Likert-type scale of 1 to 7, there were also those using only dichotomous yes-no classification. Of these analyzed scales, only one, the Concussion Symptom Inventory, offered psychometric properties that were empirically driven (McLeod & Leach, 2012).

Researchers note that while self-reported symptoms remain an essential component in clinical diagnosis, relying solely on self-reported symptoms has its limitations. Therefore, it is recommended that sports medicine clinicians use a multifaceted approach in injury assessment. The need for such an approach is due largely to an athlete's desire to return-to-play. It is contended that sports medicine professionals must differentiate between normal baseline rates of concussion-like symptoms and an acute SRC event. Since summative self-reported symptoms scales employ Likert-type scaling, they are more reliable than simple dichotomous measures of "yes" versus "no" in experiencing a given symptom. Critical to this methods effectiveness is an accurate baseline that efficiently measures symptom duration, severity, and intensity. Any variables that can cause unwanted deviation in responses to self-reported symptoms scales must be investigated and addressed in order to make safe return-to-play decisions. It is emphasized that research should focus on an investigation of baseline rates for concussion-related symptoms (Piland et al., 2010).

2.3.4 Neuropsychological Testing

There is an ongoing debate among sports medicine professionals with respect to diagnostic procedures used to determine safe return-to-play guidelines following a SRC. While neurocognitive testing has become commonly used as an objective measure for evaluating cognitive changes in post-concussion athletes, valid baseline testing is considered essential and necessary so that athletes can play an active role and serve as their own controls (Covassin, Stearne, & Elbin, 2008). Over the past 15 years the SRC management protocol has changed from a universal norm approach to a more individualized approach when dealing with concussed athletes (Lear & Hoang, 2012). Athletes are typically given a baseline assessment in the pre-season of their sport and are re-administered the same assessment after a possible concussive event. These baseline assessments take on an individualized approach, allowing the athletes to serve as their own controls during score comparison after test re-administration. This allows the practitioner to observe individualistic differences in performance, rather than evaluating every athlete on the same pre-established sex norm basis. When using normative values for an assessment as a substitute for an individuals personal baseline score, this may produce an inaccurate depiction of an athlete's condition. For this reason it is important to collect baseline scores from all athletes if at all possible.

According to Parsons, Notebaert, Sheilds, and Guskiewicz (2009), computer-based neurological testing has also found its place as a diagnostic tool. The use of computerized assessment in the evaluation of concussed athletes has been found to be a robust assessment tool in an effort to contrast pre- and post-concussion neuropsychological data. Such methods are a more favored approach compared to paper and pencil tests as they take less time to administer as a large baseline testing program. Therefore, when baseline testing is used, computerized methods may be more desirable.

While many sports medicine bodies have supported the use of standardized computer neurocognitive tests for athletes who sustain a SRC, there are those who argue the use and application of such tests. Despite the value and accuracy of computerized neuropsychological testing, it remains relatively inaccessible due to its costs and required computer platform to administer such an exam. This lack of access is magnified in the high school settings where 65% of SRCs are reported to occur (Eckner, Kutcher, & Richardson, 2010). Also, others are concerned about the practice effects of standardized testing, which may mask some of the actual SRC effects. Parson et al. (2009) suggest that when clinicians use two measurements, such as a simple change score between baseline and follow up, it is often difficult to determine the significance of the change being assessed. Of particular concern is that using simple change scores is severely limited since this method has no statistical adjustment for practice effects. However, reliable change indices (RCI) have offered noted benefits in deciphering whether the concussion measurement score differences are from meaningful change or from practice effects. This can significantly aid sports medicine clinicians in making sounder decisions in determining if a concussed athlete can return to play (Parsons et al., 2009).

Regardless of the presented concerns surrounding computerized neuropsychological tests, the National Athletic Trainers' Association's (NATA) position statement on management of SRCs concluded that standardized measures of concussion assessment were essential in assisting clinicians to make more prudent decisions in SRC assessment, as well as making return-to-play decisions (Parsons, et al., 2009). Therefore, practitioners have been encouraged to implement use of neuropsychological testing in the clinical domain as one component in SRC evaluation. There is a wide array of computerized neurocognitive assessments for practitioners to choose from and apply in their practice. Some of the more popular neurocognitive assessments include the ImPACT, Automated Neuropsychological Assessment Metrics (ANAM), Computerized Cognitive Assessment Tool (CCAT), and Concussion Resolution Index (CRI) (Straus, 2015). Each assessment purports to measure key areas of cognition, such as short-term memory, working memory, attention, concentration, visual spatial capacity, information processing speed, and reaction time. Furthermore, according to Eckner et al. (2010), the use of neuropsychological testing for assessing SRCs has offered noted benefits. These include the standardization of stimulus presentation, shorter time to administer, ability to quickly and accurately store data, easy comparison with prior test performance, as well as many equivalent forms to minimize and account for practice effects. In addition, it has been asserted that computerized neurocognitive testing tools such as ImPACT and ANAM also provide great accuracy in measuring reaction time to the millisecond. This is particularly valuable data as prolonged reaction time has been found to correlate with the persistence of concussion symptoms (Eckner et al., 2010).

Overall, neuropsychological test have demonstrated great ability and usefulness in assisting health care providers with the identification of SRC. However, an essential component, baseline testing, has presented issues. One issue found with obtaining baseline measures for athletes is the production of invalid scores in some instances following baseline assessment. There have been many hypotheses put forth as an explanation for this phenomenon. One possible explanation particularly with youth populations is that of age, with younger individuals producing more invalid scores. Lichenstein, Moser, and Schatz (2013) devised and conducted a study to assess age and test setting as factors in the production of invalid baseline scores on neurocognitive SRC assessments. Youth athletes 10-18 years of age were divided into two groups and were each given the online version of the ImPACT SRC assessment as a baseline measure. The two groups participants were divided into determined their test setting. The test setting included the site at which testing would be conducted and the size of the group in which participants would be administered the test. Participants in the large group were administered the ImPACT assessment in an athletic facility in groups of approximately 10 people, with 2 test administrators, whereas participants in the small group were administered the ImPACT assessment at a neuropsychology center in groups of 1-3 people, with 3 test administrators on-site. In regard to invalid baseline measures, younger youth athletes 10-12 years of age had significantly more invalid results compared to older youth athletes 13-18 years of age. A history of ADD or a learning disability was also found to be a significant predictor of invalid baseline scores. Athletes in this study who had ADD or a learning disability produced a greater number of invalid baseline scores than participants who did not have a history of these conditions. No differences overall were found on the basis of group size, either large or small, and invalid baseline scores. However, an age x group size interaction effect was illustrated among younger participants. There was a significantly greater likelihood of the younger youth athletes providing invalid baseline scores when tested in the large group setting as opposed to the small group setting or compared to the older youth athletes in either setting. This highlights the importance and care that must be taken when giving assessments to younger youth athletes. They require more one-on-one interaction in an environment that minimizes distractions (Lichenstein et al., 2013).

2.4 Concussion Return-to-Play

There is an ongoing debate among sports medicine professionals with respect to diagnostic procedures used to determine safe return-to-play guidelines following a SRC. As contended by Notebaert and Guskiewicz (2005), while there are a vast number of tools available for evaluation and rehabilitation of athletic injuries, there is no tool that can definitively identify the presence of a concussion or its severity. This hampers the clinician in more ways than one, especially during return-to-play program planning and the ultimate return-to-play decision. There is far too heavy reliance on the self-report symptoms by the athlete and their ability to complete tasks without symptom reoccurrence. Without other means of assessment to weigh in on this determination, there is a risk of returning an athlete to play too early. Of course, there can be devastating consequences to such a miscalculation. The approach best supported by the literature would be one that incorporates a symptom checklist, neuropsychological test, and postural stability assessment, which is also what the NATA position statement recommends. There should also be the use of baseline testing using the aforementioned during the preseason, and the same testing used once a SRC is thought to have occurred. Currently this is the best approach in safely returning an athlete to play (Notebaert & Guskiewicz, 2005).

When a sports medicine professional has determined a SRC was likely sustained, researchers recommend the return-to-play decisions follow a very specific cadence. The first level of treatment should include no activity. Once symptoms have resolved a progression to light aerobic exercise, sport-specific exercise, noncontact training drills, full contact practice, and then ultimately full return-to-play activities may occur if symptoms remain absent (McGuire & McCambridge, 2011). The stepwise return-to-play progression may be initiated and altered to fit the individual on a case-by-case basis. A more conservative approach, requiring greater time for recovery, should be taken with children due to their still developing brains (Lear & Hoang, 2012). McCrory et al. (2013) recommends those 15 years of age and younger receive this more conservative care.

2.4.1 Concussion Complications and Consequences

Before return-to-play athletes must adhere to physical and cognitive rest until symptoms resolve and then they may begin a stepwise progression, which gradually increases in exertion overtime as the athlete remains asymptomatic (Seifert, 2013). If proper diagnosis, treatment protocol, and return-to-play decisions are not properly conducted, there is a greater chance of complications. These complications are also suggested to increase relative to the number of SRCs an athlete experiences. Among these complications include second-impact syndrome (SIS), postconcussive syndrome, suicide, and retirement from elected sports. Two that are particularly important for healthcare providers to be aware of and understand are second impact and postconcussive syndromes. SIS is poorly understood, but thought to be a rapid rise in intracranial pressure due to a second head injury before the resolution of a previous one. This syndrome has been known to lead to severe disability or even death, which is why caution should always be taken before return-to-play when a SRC is suspected in an athlete. Postconcussive syndrome is an extension of symptoms persistence typically past three months (McGuire & McCambridge, 2011). This syndrome can lead to trouble with daily tasks, as well as present issues for student-athletes in the classroom. With a health care providers objective to ensure the best quality of life for a patient, decisions concerning SRCs must be made with careful calculation.

In addition to complications, there are certain consequences that may arise after sustaining a SRC. It is estimated that about 80-90% of SRCs result in quick recovery time, but there is still 10-20% that experience extended or permanent injury (Weber & Edwards, 2010). A typical factor of a traumatic brain injury (TBI) is wide spread axonal injury leading to a decrease in memory, attention span, and cognitive function. Routine tasks then become difficult without focused effort. This causes fatigue to set in, a disabling symptom common among TBIs. Patient functioning is affected by executive operational impairment. Trouble with daily living tasks is observed with this type of impairment (Fry, Greenop, & Schutte, 2010). However, consequences of a SRC fall into three categories increasing in persistence. These categories include short-term, medium-term, and long-term consequences. Short-term consequences are characterized by neurologic and cognitive symptoms that persist over the course of hours to days. Like that of the short-term, medium-term consequences include neurologic and cognitive symptoms, however these persist over the course of 7-14 days before resolution. Long-term consequences may result in lifelong persistent problems that an individual must learn to cope and adapt to. Chronic traumatic encephalopathy (CTE) may develop overtime as a consequence of repeated SRCs. CTE is represented by early onset cognitive decline due to brain degeneration, as well as psychiatric disturbance ultimately leading to dementia (Neumann, 2011; Edwards & Bodle, 2014).

2.4.2 Concussion Legislation

Due to these significant findings related to the severity and lack of regulation regarding SRCs, legislation surrounding the management of SRCs is on an upward trend. Washington State paved the way for a landslide of SRC laws after enacting the Zackery Lystedt Law in 2009 in honor of its namesake who suffered a catastrophic brain injury in a middle school football game leaving him permanently disabled. This law has purported three main tenets, which include: 1) to inform and educate youth athletes and their parents or guardians, and require them to sign a concussion information form, 2) to require removal of any youth athlete who appears to have suffered a SRC from play or practice at the time of the suspected concussion, and 3) to require any youth athlete who has suffered a SRC to be cleared by a licensed health care professional trained in evaluation and management of concussions before returning to play or practice (Concannon & Herring, 2014). With the three basic requirements of the Zackery Lystedt Law, it became model legislation for other states looking to enact similar SRC safety laws. As a result, SRC laws have been enacted in states at an unprecedented rate (Lowrey & Morain, 2014). To date, all 50 states and the District of Columbia have implemented a SRC safety law, with Mississippi being the last state to do so in 2014 (Baugh, Kroshus, Bourlas, & Perry, 2014). However, controversy has since arisen concerning the varied contents of each state's law, as they differ in their specificity, scope, and contained components. Currently, only 36 states (72%), including the District of Columbia, adhere to all 3 main tenets of the Zackery Lystedt Law. It has been concluded that a universal or umbrella SRC law, that is more well-rounded and encompassing in scope, needs to be sanctioned by lawmakers at the state level across the U.S., as well as become a priority on the federal agenda by Congress.

2.5 Sex Differences in Concussion Risk

The relationship between sex and concussion outcomes has long been debated. It has been purported by researchers that there is a discrepancy between SRC risk for males and females. Females are thought to be at a greater risk, as well as recover slower than males after sustaining a SRC. In a study by Gessel and colleagues (2007) concussion incidence was evaluated at the high school level with differences being found based on sex and sport. In high school softball and baseball players, girls and boys experienced comparable SRC rates. However, in high school soccer, girls experienced a higher rate of SRC than boys. Likewise, female high school basketball players demonstrated a higher rate of SRCs than male basketball players (Gessel et al., 2007). It has been postulated that the higher rates of SRCs in females typically found when comparing the sexes may be related to biomechanical differences inherent to sex (Gessel et al., 2007). Researchers maintain that sex differences in risk for SRC may be due to weak musculature, neuroanatomic differences, or cerebrovascular organization (Tierney et al., 2008). It is unclear at this time as to the effect of estrogen on SRC outcomes, whether it is protective or detrimental (Cantu, Guskiewicz, & Register-Mihalik, 2010). However, others suggest females, being more apt to report injuries, have biased themselves toward detection of SRCs, in turn leading to their higher rate of SRC compared to males (Seifert, 2013). Overall, the literature suggests that there are sex differences in risk for SRCs with females incurring more SRCs compared to males in sex comparable sports.

2.5.1 Symptom Differences

A variety of studies have explored the relationship between sex and SRC symptoms and related outcomes. A study conducted by Kontos and colleagues (2012) considered baseline and post-concussion factor scores to determine if they were influenced by sex differences. Findings revealed that females reported substantially more SRC symptoms at baseline than males on all four symptom clusters, which include the cognitive-sensory, sleep-arousal, vestibular-somatic, and affective domains. Also, in post-concussion symptoms females were found to score higher than males on the affective cluster, which included sadness, nervousness, and feeling more emotional. However, no other significant differences were found in the other three symptom clusters post-concussion (Kontos et al., 2012).

Consistent with, yet expanding these findings, Zuckerman et al. (2014) also evaluated sex differences in SRC symptom reporting at both baseline and following a SRC. Based on age, 122 females were matched to 122 males ranging from middle school to college age (mean age: 16.1 years). In terms of symptom severity, only the symptom of "sleeping less than usual" recorded at baseline was found to be statistically significant, with females endorsing a greater severity. All other symptoms at both baseline and post-concussion were not found to differ in severity rating based on sex. However, the total symptom score at both baseline and post-concussion was found to differ significantly between the sexes. Females were found to report more symptoms at both baseline and post-concussion leading to greater total symptom scores (Zuckerman et al., 2014).

Likewise, another research study compared SRC symptoms between males and females in a sample of high school athletes. Comparison of symptoms between male and female athletes was based on sex, symptom resolution time, and return-to-play timelines. The researchers found that male athletes reported more cognitive type symptoms, while female athletes experienced greater neurobehavioral and somatic symptom outcomes. Despite the differences in symptoms, this study noted little difference between the sexes based on severity of symptoms reported or resolution outcomes (Frommer et al., 2011).

With self-reported symptoms, there has been conflicting research between male and female athletes on symptom recovery time. Some studies have noted recovery time has not varied on the basis of the athletes' sex (Cantu, Guskiewicz, & Register-Mihalik, 2010). However, this is not a consistent finding across the literature. Zuckerman et al. (2014) noted in their study that females and males similarly returned to their baseline total symptom score within 30 days. However, the amount of time in which it took to return to symptom baseline was longer for females compared to males, requiring on average 2 more days for recovery (Zuckerman et al., 2014). More research is needed to solidify whether recovery time varies between the sexes based on self-reported symptoms.

2.5.2 Neurocognitive Performance Differences

Sex differences for neurocognitive performance and recovery time have likewise been examined. There have been differences established by researchers for verbal memory, perceptual motor speed, accuracy, and visuospatial tasks (Boden, Kirkendall, & Garrett, 1998). Covassin, Swanik, and Sachs (2007) determined female athletes demonstrated poorer visual memory performance when compared to males. In conjunction with this, Broshek et al. (2005) found that after a SRC female athletes were 1.7 times more likely to be cognitively impaired, with slower reaction times and more symptoms than their male counterparts.

Zimmer, Piecora, Schuster, and Webbe (2013) conducted a study evaluating baseline SRC scores between sports and the athlete characteristic of sex. They used the BESS, SAC, and CRI in testing. Results for the BESS indicated that overall female soccer players had the highest balance scores, whereas male basketball players had the worst balance scores. Results for the SAC demonstrated no significant differences across team, sport, or sex, and therefore, supports its use as a robust sideline measure. Women performed better on the CRI than men indicating faster complex reaction time and processing speeds (Zimmer et al., 2013). Overall, these results render the need for an individualized approach in terms of SRC testing. Assessment should perhaps be mediated by sex as there have been demonstrated neurocognitive differences.

Focusing on solely soccer athletes, Covassin, Elbin, Bleecker, Lipchik, and Kontos (2013) conducted a study to determine if there were sex differences in neurocognitive performance and symptoms after a SRC. Soccer was chosen for not only its relatively high incidence of SRCs, but also because the styles of play and rules are almost identical in regards to either sex playing the sport. Both high school and collegiate soccer players were used in this study and results demonstrated that female athletes scored lower than male athletes on visual memory and reported more symptoms at 8 days post-injury. These results are controversial with respect to similar studies. Two factors, which require further investigation include BMI and neck strength as they may mitigate sex differences. However, age remains a factor that needs to be examined more closely as well.

2.5.3 Age and Sex Interaction Effect

To date, limited research has evaluated the combined effect of sex and age on SRC outcomes. Covassin and colleagues (2012) examined the interactive effects of age and sex with symptoms, neurocognitive testing, and postural stability in concussed high school and collegiate athletes. These outcomes were chosen for their alignment with the current concussion consensus statement, which recommends a multifaceted approach in handling SRCs (McCrory et al., 2013). The between-subjects interaction of sex and age in the BESS data indicated female high school athletes performed better than male athletes. However, the results varied in the collegiate population, with females performing worse than their male counterparts. No main effects for age or sex were found to be significant on the BESS. The symptom scores demonstrated there was a between-sex difference for SRC symptoms. At each time point, female athletes reported more symptoms than males. Age and the interaction of age and sex were not significantly different in relation to symptoms. There were no significant differences determined with symptoms at baseline, however a closer look at symptom reporting may be indicated for high school and collegiate athletes. Neurocognitive performance with the interaction effect of age and time was significant within-subjects. At 2 days and 7 days post-concussion, collegiate athletes performed better on verbal memory than their high school counterparts. Reaction time and processing speed were not found to be significantly different based on age. Between-groups neurocognitive performance with the effect of sex revealed males performed better than females on visual memory. However, verbal memory, motor processing speed, and reaction time did not show a difference based on sex, as well as there was no interaction between sex and age on any of the neurocognitive factors (Covassin et al., 2012). Although, individually, the factors of sex and age have been demonstrated to affect performance and symptom reporting, there has not been an age x sex interaction affect found on any components of SRC assessment.

With the substantial evidence of sex differences in both symptom reporting and neurocognitive testing at both baseline and post-concussion, new and emerging SRC assessment tools should be evaluated to determine if they also present differences based on sex. Some studies have asserted that there are no differences in performance at a young age due to insignificant brain maturation and development. It has been purported that differing exists with cognitive growth patterns associated with aging, making males more successful in visual and spatial tasks and females more oriented for verbal and literacy tasks once their brains begin maturing during adolescence (Sharma et al., 2014). Therefore, it is important to establish whether symptom reporting or neurocognitive testing differences exist before an athlete's formative years (i.e., prior to 13 years). Without established normative values for an assessment, outcomes comparison may lead to inaccurate interpretation of results. Therefore, testing of each new youth SRC evaluation tool for sex differences is an essential step that should be taken prior to implementation.

2.6 Age Differences in Concussion Outcomes

2.6.1 Symptom Differences

Age has been purported to have an effect on SRC outcomes. Age differences have been identified at the youth, high school, and collegiate level. It has been asserted that symptoms vary by age, in both number reported and type. In a study by Kerr et al. (2016b), the number of reported symptoms was highest in high school football athletes, followed by college football athletes, and then youth football athletes. On the other hand, when analysis was restricted by category of symptoms, other patterns emerged. Kerr et al. (2016b) found that no difference existed based on migraine symptoms among youth, high school, and collegiate athletes. Youth were found to report fewer mean numbers of cognitive, neurocognitive, and sleep symptoms as compared to high school and collegiate populations (Kerr et al., 2016b). Kontos et al. (2012) expanded on this and found that high school athletes, when compared to their collegiate counterparts, reported more baseline symptoms for the cognitive-sensory and vestibular-somatic symptom factors. However, collegiate athletes scored higher on the sleep-arousal symptom factor than high school athletes. The authors purported this difference in sleep-arousal could be due to increased academic and sport demands (Kontos et al., 2012). The above studies demonstrate that symptoms vary with age and should be accounted for in this manner by practitioners.

2.6.2 Neuropsychological and Electrophysiological Function

In a study by Baillargeon, Lassonde, Leclerc, and Ellemberg (2012), neuropsychological and electrophysiological function were evaluated based on age and lifespan. Three age ranges were used to represent children, adolescents, and adults. Half of the participants included were concussed at the time of testing, and all participants had been concussed in the year before testing occurred. All athletes were asymptomatic at time of testing. The results of this study showed that concussed athletes, even though asymptomatic, had a reduction in amplitude of the P3b component. This component essentially indicates the available attentional resources, which update working memory information. This phenomenon was seen across age groups in concussed subjects. Adolescents seemed to be the most vulnerable age group for deleterious effects as they were the only group to have persisting deficits in working memory as assessed by a neuropsychological task. They also experienced the greatest amplitude reduction of P3b out of all three groups (Baillargeon et al., 2012).

2.6.3 Neurocognitive Performance and Recovery Differences

Neurocognitive differences have also been found to exist between the various age populations. One study using the ImPACT assessment tool, assessed neurocognitive and symptom scores between two groups composed of high school and collegiate athletes, respectively. Neurocognitive scores were assessed on visual motor (processing) speed, reaction time, visual memory, and verbal memory. The high school group scored significantly better on visual motor (processing) speed, while the college group scored significantly better on reaction time. No statistically significant difference was found between the groups on visual and verbal memory scores. The PCSS scores were also found to be similar between groups. In terms of recovery and return to baseline, it was found that there were group-based significant differences dependent on the multifarious neurocognitive components. Consistent with literature, the younger group took more days for their neurocognitive scores to return to baseline. On average it took approximately 2.5 more days for verbal memory, 2.4 more days for visual memory, 2.1 more days for reaction time, as well as 2.0 more days for their symptoms to return to baseline values compared to the older group (Zuckerman et al., 2012).

Other researchers have also found that high school athletes are also slower to recover than college (McClincy, Lovell, Pardini, Collins, & Spore, 2006). Specifically memory and reaction time deficits have were reported in high school athletes 7 to 14 days and 14 to 21 days post-concussion, respectively (McClincy et al., 2006). Iverson, Brooks, Collins, and Lovell (2006) also noted that clinical impairment is present on 2 or more neurocognitive measures in 37% of high school athletes 10 days post-concussion (Iverson et al, 2006). Alternatively, college athletes recovered within 5 days of a SRC on auditory attention and visuomotor processing speed (Macciocchi, Barth, Alves, Rimel, & Jane, 1996). Also in agreement, Echemendia, Putukian, Mackin, Julian, and Shoss (2011) found collegiate athletes to be free of neurocognitive deficits within 7 days of a SRC. This rapid resolution of symptoms in college athletes has been attributed to anatomic, behavioral, and physical differences in the brain of adults versus adolescents. Researchers suggest, these, along with the susceptibility to head trauma of adolescent brains are the reason for the reported age variation (McCrory, Collie, Anderson, & Davis, 2004).

Similar assertions about recovery and return-to-play were put forth in a study assessing SRCs among football players at the youth, high school, and collegiate levels. Differences were found on the basis of return-to-play, varying as a function of competition level. Youth and high school populations were found to have a longer recovery period and subsequent return-to-play than collegiate populations, with more athletes at the younger levels requiring greater than 30 days before cleared to full sport participation. Conversely, youth athletes also had the highest percentage of athletes returned to play in less than 24 hours. A significant difference was also found in this short return-to-play between youth and high school populations, with far fewer high school athletes being returned-to-play within 24 hours (Kerr et al., 2016b).

An essential component in head injury evaluation and the subsequent return-to-play decision is the results from administration of SRC assessments. In the youth population, this component is severely lacking due to the limited number of age-appropriate SRC assessment tools. Currently, only three assessments are considered to be youth specific SRC assessment tools. These youth assessment tools include the Child SCAT3, MACS, CogSport for Kids, and ImPACT Pediatric. However, these assessments have yet to be assessed for their psychometric properties, leaving them to produce uncertain results. This demonstrates the demand for further research in the area of youth concussion evaluation and assessments, as well as highlights the need for new youth assessments creation and development to aid in accurate diagnosis and decision-making.

2.7 Concussion Evaluation in Youth Athletes

Despite the increasing investment in protective sports equipment, ensuring annual preseason medical physicals, and high school and youth athletic preseason and post-concussion testing programs, SRCs remain a significant health risk for children (Moser, 2007). There have been substantiated links between SRCs and cognitive deficits, sleep disturbances, depression, irritability, difficulty concentrating and remembering, and even suicidal thoughts. Multiple researchers suggest that concussions in children and adolescents may be associated with a slower recovery time (Broglio & Puetz, 2008; Gagnon, Galli, Friedman, Grilli, & Iverson, 2009). Based on these concerns, it is important to accurately identify the presence of concussion, as well as determine what care is necessary and develop an individualized and interdisciplinary treatment plan by health care providers. Currently there are limited SRC assessment tools available for evaluation, that have been designed specifically for use in youth populations. Insomuch, research studies have demonstrated that few of these assessments achieve consistent acceptable results in their evaluation of concussed youth. Therefore, there is a dire need for more and better youth specific SRC assessment tools.

2.7.1 Child-Sport Concussion Assessment Tool 3 (Child-SCAT3)

It is known that the diagnostics utilized to assess SRCs are limited and often fail to properly diagnose the incidence of this condition. Researchers suggest that more reliable methods are needed to certify the accuracy of baseline testing and as a result, ensure better diagnostics during SRC evaluation (Frommer et al., 2011). Recently, there has been the creation and development of assessment tools specifically designed for use in youth populations. Initially SRC assessment tools were developed for athletes 13 years of age and older. However, these tools contain language and testing components that have been proven too advanced for younger populations, 12 years of age and younger. Therefore, there was a need for creation of age appropriate tools for these youth athletes. One such measure that has emerged is the Child-SCAT3. The Child-SCAT3 is the most up-to-date version of the SCAT and is expressly for children between the ages of 5-12. Its components include a symptom severity score, orientation, immediate memory, concentration, and delayed recall. Balance tests are also performed using a modified version of the BESS (Child SCAT3, 2013). Portions of the SCAT2, a version before the SCAT3, have been validated through various studies. These include the symptom assessment-PCSS, SAC, and certain aspects of the BESS. Both the SAC and BESS are separate SRC tools embedded within the SCAT assessments. Further validation of this assessment would be required before use in a study.

2.7.2 Balance Error Scoring System (BESS)

One dynamic practitioner's must take into consideration when administering assessments to youth is their validity with this younger age group. Quatman-Yates et al. (2014) explored the utility of the BESS for children and adolescent populations, ages 8-18, in a study. Results revealed that age was related to outcome scores, with younger participants recording more errors than older participants. There was a significant correlation between age and single-leg firm, tandem firm, and single leg foam stances, as well as total BESS score. Also significantly correlated to age among neurocognitive performance were visual motor speed, reaction time, and impulse control. In this study, assessment was also conducted to evaluate the effect of injury on BESS outcome scores. Significant differences were noticed on the single-leg firm stance, tandem firm stance, single-leg foam stance, and total BESS score. The other stances proved to have similar outcomes between injured and healthy participants. Even with the statistical significance seen in a few stances, the researchers warn against the clinical significance of these results, as the overall mean BESS scores between the groups only varied slightly. These results, however, indicate that the use of the BESS with children and adolescents may be limited. With younger age children producing more errors even when healthy, the effects of a SRC may be masked when post-injury scores are compared to baseline scores. The BESS should always be used in conjunction with other SRC assessments, as it only assesses one aspect of this multifaceted condition (Quatman-Yates et al., 2014).

2.7.3 King Devick (KD)

With SRCs remaining difficult to diagnose despite the plethora of research being conducted concerning them, researchers are creating new tools to explore their value in SRC testing. Currently, no single SRC assessment tool is recommended for its sole use in the diagnosis of a SRC. Therefore, there is still a need to better define and select what factors should be included in the assessment of SRC. In a study by Galetta et al. (2015), the benefit of adding a vision component to the overall assessment of SRC was considered for its contribution in diagnosis. Participants included 243 youth, 5-17 years old, and 89 collegiate athletes, 18-23 years old, who were tested at baseline and post-concussion using a vision, cognitive, and balance measure, by means of the King Devick (KD), SAC, and a timed tandem gait, respectively. The KD is composed of four cards, where the first card is a demonstration/practice card, followed by 3 test cards each subsequently increasing in difficulty. In analysis of baseline scores, it was found that every measure demonstrated improved scores as a function of increasing age. Particularly in the KD, the comparison of test card one to test card 3 revealed older age as a significant contributor to better performance scores. Post-concussion testing results demonstrated that two of the three measures, including the KD and timed tandem gait, produced significant score changes from baseline. It was found that KD scores of concussed athletes decreased by 5.2 seconds on average, whereas the matched controls demonstrated a 6.4 second improvement in their scores on average. In ability to distinguish concussed versus control group membership, the KD was able to correctly identify a concussion 92% of the time, the timed tandem gait 87% of the time, and the SAC 68% of the time. In assessing combined accuracy of measures, when all three measures were grouped together they were able to correctly distinguish concussion 97% of the time, the SAC and timed tandem gait 88% of the time, and the timed tandem gait and KD 98% of the time. This expresses the value of the KD alone, with the timed tandem gait increasing the probability of correct SRC identification by only 6% (Galetta et al., 2015). These findings suggest the KD may be or become a valuable tool used in the assessment of SRC. However, these results only reflect the findings of one study, with others have produced controversial results concerning the KD.

2.7.4 Vestibular/Ocular Motor Screening (VOMS)

Another tool that has shown promise in aiding in concussion identification is the Vestibular/Ocular Motor Screening (VOMS). This assessment assesses vestibular ocular function for dysmetria, nystagmus, smooth pursuits, and fast saccades through gaze stability, near-point convergence, and gait/balance testing (Corwin et al., 2015). This tool has experienced brief study with youth populations. Corwin et al. (2015) examined vestibular deficits in 247 older and younger youth athletes 5-18 years old following SRC. In this sample, vestibular deficits were demonstrated in 81% of the sample. Abnormal vestibular ocular reflex and tandem gait was exhibited upon initial concussion evaluation in 69% and 80% of this population, respectively. It was observed that the athletes with vestibular deficits had an extended recovery, taking a greater amount of time to return to school, as well as be fully cleared for sport participation compared to those who did not have these deficits. In relation to neurocognitive scores obtained through ImPACT testing, older youth with vestibular deficits demonstrated lower percentile scores on verbal memory, processing speed, and reaction time than those without vestibular deficits. Also, in terms of neurocognitive outcomes and recovery, scores for verbal memory, visual memory, and processing speed took three times as long to return to baseline in youth athletes with vestibular deficits. There was also a correlation noticed between prior history of SRC and likelihood of developing vestibular deficits. In this study, vestibular deficits were revealed in 81% of youth with one or two prior SRCs and 100% who had experienced three or more prior SRCs. Health care providers should utilize this information in their evaluation of athletes with SRCs and in monitoring their recovery, which may be prolonged (Corwin et al., 2015).

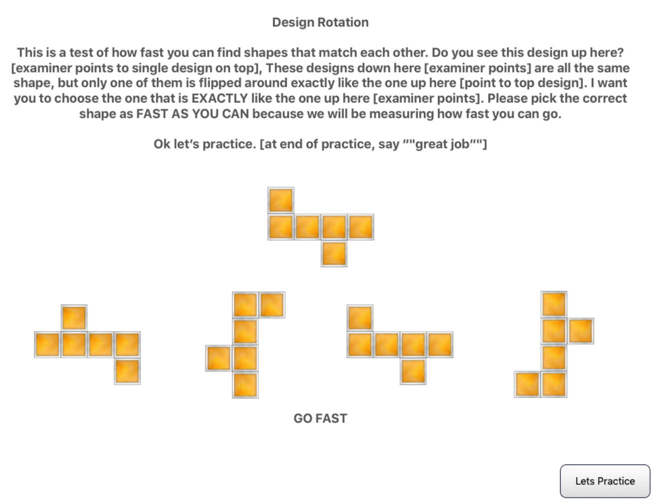
2.7.5 Immediate Post Concussion Assessment Cognitive Testing Pediatric (ImPACT Pediatric)

Another SRC assessment tool that has been newly created for youth is the ImPACT Pediatric test (kid's edition). It was developed for administration in youth 5-12 years of age as both a baseline and post-concussion measure. The ImPACT Pediatric is shorter than the ImPACT, used for high school, college, and professional athlete populations, requiring only 10-15 minutes to complete. This SRC assessment tool is composed of three primary sections. The first section is a demographic questionnaire, which includes general information (i.e name, birthdate, gender), education (i.e. repeated or skipped a grade in school), and medical history (i.e. number of previous SRCs, attention deficit disorder, learning disability, depression, etc.). The second section is a 12-question symptom inventory completed by both the parent/guardian and the youth athlete. These symptom inventories are the same with the exception that the parent/guardian answers the questions based on their observations of their child, whereas the youth athlete answers based on how they feel themselves. The parents/guardians and youth athletes simply indicate yes or no if they have been experiencing a symptom or not, regardless of the degree or severity. The final section examines neurocognitive function through the evaluation of sequencing/attention, word memory, visual memory, and reaction time.

These areas of assessment are contained in test modules within the exam. Test modules include word list, design rotation, stop and go!, memory touch, picture match, color match, word list-delayed recall, word list-delayed recognition, and picture match-delayed recognition. Each of these test modules are presented in a game-like format in order to keep the young athletes engaged throughout the assessment. The first module is the word list, which measures attentional processes and immediate verbal memory. In this module five words are presented to the participant on the screen one at a time over the course of a few seconds. The participant is then asked to recall the five words in any order. Identification of the five words again is required after completion of all other test modules (approximately 8-10 minutes).

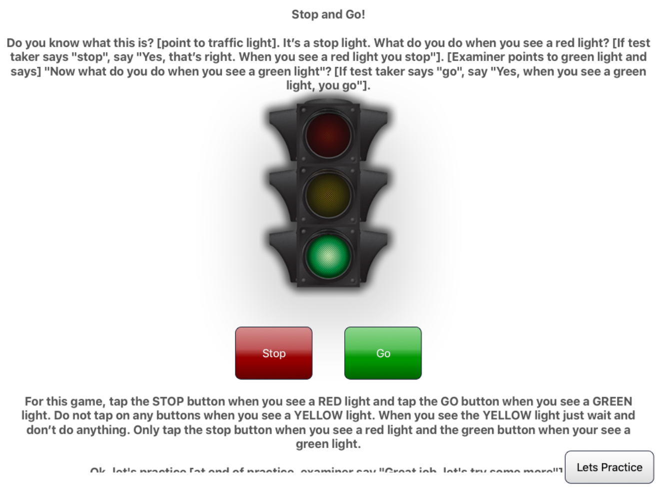
The second module is design rotation, which assesses visuospatial skills and response speed. In this module 10 designs are presented on the screen one at a time with four of the same designs presented under them. All the designs will be rotated or flipped, except the exact match. Participants are asked to tap on the design that matches the design presented above exactly. They are also asked to make the correct decision as quickly as possible (Figure 2).

Figure 2. *ImPACT Pediatric- Design Rotation*



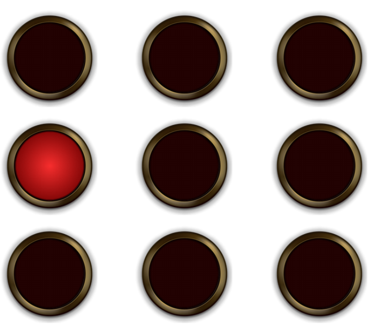
The third module is called Stop and Go! and measures cognitive speed and impulse control. This module displays the image of a traffic light and instructs the participant to tap the word “go” when they see a green light flash, “stop” when they see a red light flash, and nothing at all when they see a yellow light flash. Participants are also instructed to make their selection as quickly as possible after seeing the light flash a particular color (Figure 3).

Figure 3. *ImPACT Pediatric- Stop and Go!*



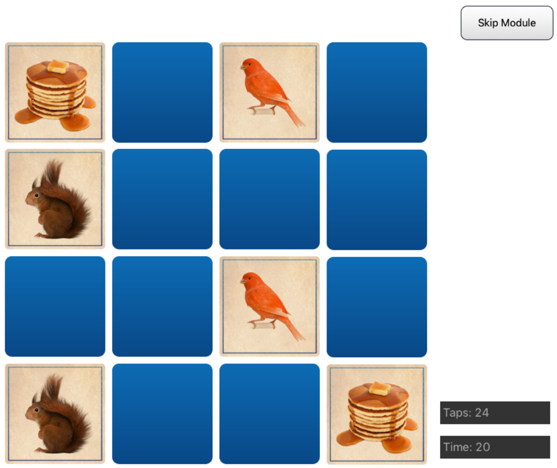
The fourth module is memory touch assessing nonverbal spatial span. In this module a grid of 3x3 circles is presented. A certain number of the circles then light up one at a time in a particular pattern, beginning with 2 circles. Upon completion of the pattern, participants are asked to tap the circles in the same order they lit up originally. This task gets increasingly harder as the string of circles that light up during a single pattern becomes longer (Figure 4).

Figure 4. *ImPACT Pediatric- Memory Touch*



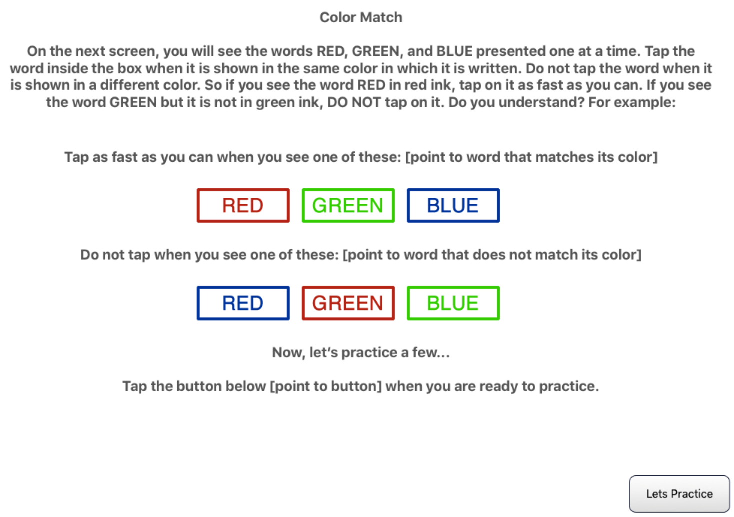
The fifth module is called picture match. Picture match is similar to the card game memory and measures cognitive speed and immediate memory. A grid of 4x4 card tiles is presented to participants face down. The participants are then instructed to tap on any two tiles to flip them over. If the tiles contain the same picture they will remain facing up, but if they do not, both will flip back down. The object is to get all the tiles matched, and therefore facing up, as quickly as possible. A total of 3 different grids are presented for participants to complete. This module like the word list also has a delayed recall component where participants will be asked if certain face cards presented on the screen were also card tiles from the picture match game. This portion will be administered after all other modules are completed (Figure 5).

Figure 5. *ImPACT Pediatric- Picture Match*



The sixth and last module is color match. In this module either the word "red", "blue", or "green" will be presented inside a rectangle on the screen. If the color of the word and box around the word matches the word displayed in the middle, then the participants are to tap the screen as quickly as possible. If the color of the word and box around it do not match the word displayed in the middle, the participants are instructed to not tap the screen. Each word/color combination is presented for less than a second at a time (Figure 6). After this module is completed the word list and picture match delayed recall tasks will be presented as the last components of the ImPACT Pediatric assessment.

Figure 6. *ImPACT Pediatric- Color Match*



The reliability of the ImPACT Pediatric has been assessed in a previous study of youth ice hockey and soccer athletes who underwent testing at 1 week and 1 month test intervals (Moore, Murphy, Seramur, & Lovell, 2015). From this the test-retest reliability coefficients (ICCs) were calculated for the components composing the assessment. These ICC values ranged from .46-.89, all reaching statistical significance at a p-value <0.001 (Table 2). Validity of this tool was also assessed through multiple studies producing acceptable results all purporting the ImPACT Pediatric does measure what it is intended to measure (Lovell, 2015). There is no reading level requirement for completing the examination, as a trained research assistant who reads and explains every test module to the youth in a one-on-one format administers the assessment (Lovell, 2015). The ImPACT Pediatric should not be used to replace medical treatment, however it did recently received FDA approval for its use clinically. It is currently the only computerized neurocognitive assessment specific for youth populations that has been approved by the FDA and has now been released for public use. As a result, other youth SRC measures should be validated using the ImPACT Pediatric neurocognitive test.

Table 2. *ImPACT Pediatric- Test-Retest Reliability Coefficients*

Test Module	ICCs	Test Module	ICCs
Word List Immediate Recall Number Correct	.83	Memory Touch Total Sequences Correct	.79
Word List Delayed Recall Number Correct	.82	Memory Touch Highest Sequence	.72
Word List Delayed Recognition	.89	Stop and Go Number Correct	.63
Design Rotation Number Correct	.67	Stop and Go Average Time	.71
Design Rotation Average Time	.61	Picture Match Average Taps	.46
Memory Touch Number Correct	.81	Picture Match Average Time	.54

2.7.6 Immediate Post Concussion Assessment Cognitive Testing Quick Test-Pediatric Version (ImPACT QT-PV)

Yet another neurocognitive SRC assessment tool developed and being tested in youth populations for its clinical merit is the ImPACT Quick Test - Pediatric Version (ImPACT QT-PV). The ImPACT QT-PV is a quick 5-minute iPad assessment used during baseline and post-concussion testing. It was specifically developed for use in youth populations ranging from 6-11 years of age. This assessment is more useful as a "screening test," and should mainly be used to identify if further examination is needed before immediate return-to-play. It is not nearly as extensive as a full computerized neurocognitive test or comprehensive neuropsychological evaluation, and therefore should not be used as a replacement for these more thorough assessments. The ImPACT QT-PV measures neurocognitive functioning through symbol matching, letter memory, number sequencing, and reaction time components. Previous to beginning the assessment, a short inventory of observed signs and reported symptoms are recorded by the test administrator and athlete, respectively.

The first module of this assessment is symbol matching where 5 simple symbols are paired with a number 1 through 5. This starts out easy with the participant seeing each number with the corresponding symbol above it on the screen, and progresses to where the symbols disappear and the participant must choose the correct number for each symbol from memory

(Figures 7 and 8).

Figure 7. *ImPACT QT-PV- Symbol Matching*

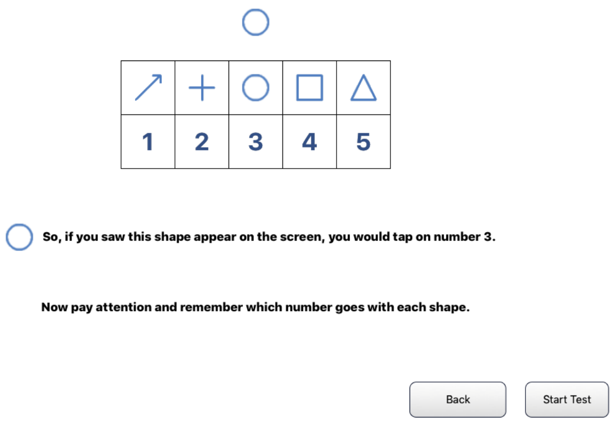
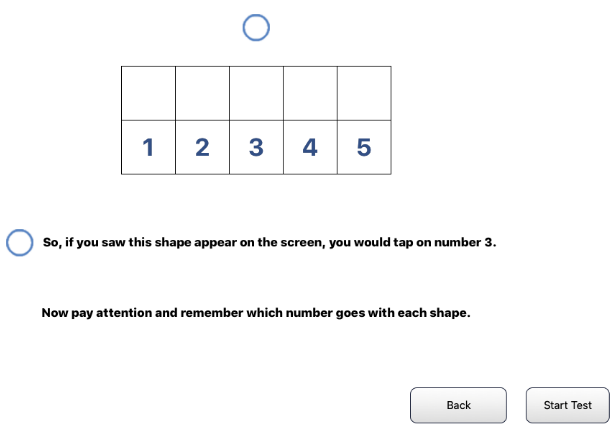
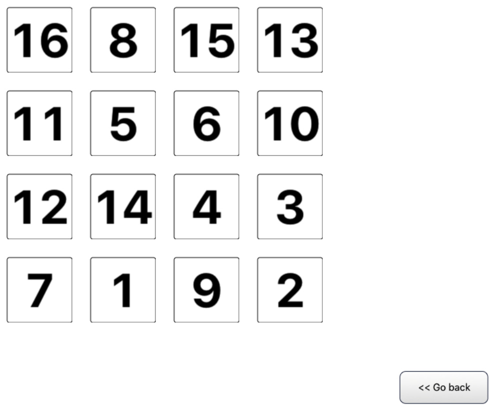


Figure 8. *ImPACT QT-PV- Symbol Matching 2*



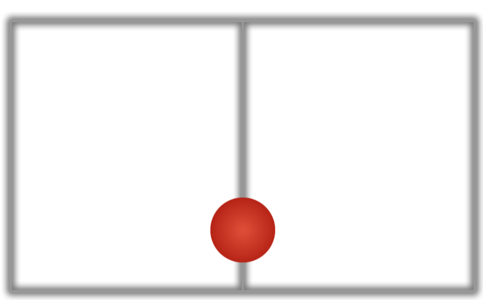
The next module includes letter memory and number sequencing presented in an alternating array, with this configuration being repeated three times. The pattern begins with three random letters being displayed for a few seconds on the screen for the participant to memorize. Next, the participant is presented with a 4x4 grid containing the numbers 1 through 16 on blocks in a scrambled arrangement. Participants are then instructed to counts backwards from 16 down to 1, tapping the blocks in the correct order (Figure 9). Last, the participant is asked to recall and select the three letters originally displayed to them on the screen. This pattern will then be repeated containing new letters and a different arrangement of numbers.

Figure 9. *ImPACT QT-PV- Number Sequencing*



The final module in this assessment assesses reaction time via the participant tapping a circle that is slowly moving around the screen. The circle begins the color red, however it will randomly change to the color green for a couple seconds at times, before turning back to the color red. Participants are instructed to quickly tap the circle while it is green, every time it turns green, before it flips back to the color red. This module contains three phases that increase in difficulty, as the pattern the circle travels becomes more, faster, more challenging, and less predictable (Figure 10).

Figure 10. *ImPACT QT-PV- Eyetracker*



The ImPACT QT-PV has yet to undergo validity testing for normative baseline values. Baseline testing has been recognized as an important component in concussion testing as it takes on an individualized approach during re-assessment. Also, it is important to determine normal values for youth on this assessment and its components to better understand the range of scores youth most typically record. Therefore there is a need for validity testing against an established measure, such as the ImPACT Pediatric, to ascertain if this tool could become a valuable option in SRC testing.

CHAPTER 3

METHODOLOGY

3.1 Purpose

The primary focus of the study was:

1) To collect normative values for both the ImPACT QT-PV and the ImPACT Pediatric
2) To determine the concurrent validity of the ImPACT Quick Test-Pediatric Version (ImPACT QT-PV) with the ImPACT Pediatric
3) To establish the reliability of the ImPACT QT-PV

The secondary focus of this study was to address exploratory questions pending the appropriate sample sizes were obtained. These exploratory questions included:

1) Are there age differences (i.e., 6-8 years, 9-11 years) in cognitive performance?
2) Are there sex differences in cognitive performance in youth athlete's age 6-11 years old?

Methodology will be discussed in this section including the study's research design, participant pool, instrumentation employed, operational definitions, procedures, and statistical analysis.

3.2 Research Design

This study is classified as a cross-sectional study. The ImPACT QT-PV and ImPACT Pediatric, are similar in their content and assessment of baseline and post-concussion cognitive functioning, and were specifically developed for use in youth populations. However they vary slightly, most obviously in test length. These measures were administered within the same testing period in a counterbalanced order. This allows each subject to receive a baseline score for both assessments, while limiting the affect in which the administration order may have on score outcomes. The independent variables are age and sex. Age will be defined as 6-8 years old and 9-11 years old. Data was collected from April 2016 – March 2017.

3.3 Participants

The study population of interest was comprised of 240 male and female youth athletes from the States of Michigan, Tennessee, and Alabama. Of the participants 202 were used in general analysis, while 38 participants were used solely for test-retest reliability analysis. This sample size was determined after reviewing similar concurrent validity studies and gaging the appropriate number of participants needed. There has not yet been an established method for calculating sample size for a validity study *a priori* and the literature available demonstrates a variety of means used in determining sample size (Anthoine et al., 2014). For this particular study we decided that based on literature 15 subjects per construct would be appropriate and the number of constructs would be based on the validated measure of this study, the ImPACT Pediatric. We extracted 10 constructs of interest from the ImPACT Pediatric, therefore totaling to a need of approximately 150 subjects.

A youth football organization, karate club, two private schools with a variety of sport programs, and a company hosting traveling outdoor basketball tournaments were recruited for participation in this study. The youth football organization was located in Mid-Michigan, the karate club was located in middle Tennessee, and the private school was located in North Alabama. The company hosting traveling outdoor basketball tournaments had tournaments all over the State of Michigan, with data collection being conducted at three of these locations. The ages of all participants ranged from 6-11 years old. All data collection sites were chosen for convenience and accessibility purposes. The youth football organization used in this study was also selected based on the prevalence of concussive injuries in the sport (Mayo Clinic, 2014).

3.3.1 Inclusionary Criteria

In order to be eligible for participation in this study, male and female participants had to meet the following inclusionary criteria: 1) must be between the ages of 6-11 years of age, 2) their primary language must be English or they should be fluent in English, 3) must be a participant on a youth sports team, 4) any athlete that has a history of concussions is allowed to participate in the study as long as they have been symptom free for 6 months from their last concussion, and 5) athletes with a 504 designation at school or attention deficit/hyperactive disorder will be included in the study.

3.3.2 Exclusionary Criteria

Athletes were excluded based on the following criteria: 1) male and female youth athletes will not be allowed to participate in this study if they have documentation of a known special education diagnosis other than a 504 designation at school or attention deficit/hyperactivity disorder, 2) are not primary English speakers or proficient in the English language, 3) are currently suffering from or being treated for a concussion, and 4) those athletes who have undergone brain surgery or had a severe history of intracranial pathology (e.g., subdural hematoma) as determined by a positive CT scan or MRI will be excluded from the current study, and 5) if they have any known physical or psychological impairment that would affect their ability to perform the tests (i.e. down syndrome). Participants were not excluded for any previous history of concussion if the concussion was sustained and symptoms resolved prior to 6 months from time of recruitment.

3.4 Operational Definitions

CONCURRENT VALIDITY – Measure of the extent a particular test correlates to a similar, already validated test. Both tests must be given relatively close together timing-wise.

CONCUSSION – Complex pathophysiological process affecting the brain, induced by biomechanical forces resulting from a blow to the head, or other part of the body that resulted in an alteration in mental status and one or more of the following symptoms: headache, nausea, sensitivity to light, memory loss, dizziness, fogginess, confusion, tinnitus, sleep disturbances, blurred vision, or loss of consciousness (McCrory et al., 2013).

COUNTERBALANCED MEASURES – Measures administered in an alternating arrangement in order to ensure the results are not directly related to the order of measure administration. Simply illustrated, some participants would be administered the ImPACT QT-PV first, then the ImPACT Pediatric, while others would be administered the ImPACT Pediatric, then the ImPACT QT-PV.

NORMATIVE DATA – Data collected from a large sample population, from which a baseline range for a measurement may be obtained and used for reference and comparison.

YOUTH ATHLETE – Defined as a person between the ages of 6-11 years, who participates in an organized sport.

3.5 Instrumentation

Two youth concussion assessments were used for primary instrumentation in this study. Both youth concussion assessments are applications for use on an iPad. There is no reading level requirement for completing either the ImPACT QT-PV or ImPACT Pediatric assessment, as a trained research assistant administered each test measure. The four research assistants who administered the assessments were trained in administering both assessments. They shadowed the primary researcher before being allowed to administer the assessments themselves, as well as were monitored during administration of their first two assessments to ensure they were following proper protocol. During testing, the research assistant read and explained every test module to the youth athlete in a one-on-one format. However, youth were required to identify and speak English as their primary language. This was addressed during the screening process where examination of inclusionary/exclusionary criteria occurred.

3.5.1 Immediate Post Concussion Assessment Cognitive Testing Quick Test-Pediatric Version (ImPACT QT-PV)

The ImPACT QT-PV is a concussion evaluation tool developed for use in youth 6-11 years of age. This assessment processes the cognitive areas of memory and reaction time for youth through module components including symbol matching, letter memory, number sequencing, and red-to-green circle tap. The ImPACT QT-PV is a short application for an iPad, designed to be portable and easily assessable for use on the sideline at sporting practices and events in case of a concussive injury. However, it is a more condensed test, taking only 5-10 minutes to complete by subjects. With that being said, this test should typically be used for "screening" purposes only to identify if further examination is warranted before return-to-play. This test should not act as a replacement for a full comprehensive neuropsychological evaluation or computerized neurocognitive test, as these assessments are more well-rounded in their examination of SRC. This tool is currently undergoing continued testing and has not yet been released for public use.

3.5.2 Immediate Post Concussion Assessment Cognitive Testing Pediatric (ImPACT Pediatric)

The second assessment that will be used in this study is the ImPACT Pediatric. This assessment, like the ImPACT QT-PV, is an iPad-based concussion assessment tool accessible through an application. The ImPACT Pediatric test is a brief application for the iPad developed for administration in youth 5-12 years of age as both a baseline and post-concussion measure. However, we will only test children age 6-11 years for this study. This tool has already undergone validity and reliability testing, reaching acceptable levels. In a previous study the test-retest reliability coefficients (ICCs) were calculated for the components composing the assessment. All ICCs reached statistical significance at a p-value of <0.001, with ICC values ranging from .46-.89 (Lovell, 2015). Multiple studies also assessed the validity of this tool, purporting it produced acceptable results and indeed measured what it is intended to measure (Lovell, 2015). Although longer than the ImPACT QT-PV, it is shorter than the ImPACT test, only requiring 10-15 minutes to complete. It assesses important elements of cognition that are often affected by concussion, including attention, memory, visual motor speed, and reaction time. These areas of assessment are contained in test modules within the exam. The ImPACT Pediatric test modules include word list, design rotation, stop and go!, memory touch, picture match, word list-delayed recall, word list-delayed recognition, and picture match-delayed recognition. Each of these test modules are presented in a game-like format in order to keep the youth engaged throughout the assessment. The ImPACT Pediatric also includes a demographic questionnaire and symptom inventory to be completed by both the parent and youth athlete (Lovell, 2015). The ImPACT Pediatric recently received FDA approval and is now available and employed for public use.

3.6 Data Collection Procedures

Institutional Review Board approval for the study and use of human participants was obtained from Michigan State University. Recruitment of youth athletes occurred by first contacting youth data collection sites and their corresponding program administrators for their participation. The primary researcher then met with program administrators to explain the study and get their involvement and assistance throughout the data collection process. Also the principle of the two private schools were contacted, given an explanation of the study, and invited to have their school participate. Once all parties agreed, commencement of recruitment of youth athletes began. Parents/guardians were emailed or distributed in person consent forms. Parental/guardian consent was obtained prior to any data collection. Data collection dates and times were then arranged with the organizations and clubs for testing. Data collection took place at either the school or practice facility. Participants were administered the assent form, explained the study, and asked if they had any questions. Each participant was assigned to a trained research assistant for one-on-one administration of the iPad assessments. Once assent was obtained, potential youth participants were then screened for inclusionary/exclusionary criteria.

Participants were randomly assigned in a counterbalanced fashion the ImPACT QT-PV and the ImPACT Pediatric. These assessments were administered to each participant back-to-back with three minutes between administration of the first and second assessment. Upon back-to-back completion of the assessments, youth athletes were given a $5.00 gift card as a token of appreciation. Youth athletes had to complete both assessments in order to receive a gift card. Gift cards were purchased through a Kinesiology department grant at Michigan State University, as well as some were provided by the ImPACT company who also received the data. Youth athletes were allowed at any point in time during testing to withdraw from the study and discontinue participation. A portion of the participants received a follow-up assessment, where they again completed the ImPACT Pediatric and ImPACT QT-PV one week after taking the assessments the first time. These data were used in the test-retest reliability portion of the study.

3.7 Data Analysis

Our data was analyzed using the IBM Statistical Package for the Social Sciences (SPSS) 23.0. General descriptive (i.e. means, standard deviations, and frequencies), and inferential statistics were conducted to summarize the data and outcome variables. The constructs of interest within the ImPACT Pediatric included the word list immediate recall number correct, word list delayed recall number correct, word list delayed recognition number correct, design rotation average time, design rotation number correct, stop and go! average time, stop and go! number correct, memory touch highest sequence, memory touch number correct, memory touch sequences correct, picture match average taps, picture match average time, picture match correct delayed recognition, color match average time, and color match number correct. The dependent variables for the ImPACT Pediatric included attentional processes, immediate memory, visuospatial skills, response speed, cognitive speed, impulse control, and nonverbal spatial span. The constructs of interest within the ImPACT QT-PV included symbol match correct visible average answer time, symbol match number correct hidden, counting average correct, three letters correct, eye tracker rectangular average time correct, eye tracker figure eight average answer time correct, and eye tracker complex average time correct. The dependent variables for the ImPACT QT-PV included reaction time and memory. The independent variables for both the ImPACT Pediartic and the ImPACT QT-PV were age, divided into younger youth (6-8 years old) and older youth (9-11 years old) and sex, divided into males and females. The p-value was set prior at 0.05. The rest of the specific data analyses are reported below.

3.7.1 Validity Assessment

Data was analyzed using correlations to determine if the ImPACT QT-PV accurately measures neurocognitive function in youth, as does the ImPACT Pediatric, which has already been established as a valid measure. Correlations were performed between modules in the ImPACT Pediatric and ImPACT QT-PV as displayed in Table 3.

Table 3. *Correlation Analysis between Modules of Interest*

Construct Tested	ImPACT Pediatric	ImPACT QT-PV
Memory	Word List- Immediate Recall	Symbol Match- Memory Component
		Three Letter Memory- Memory Component
	Word List- Delayed Recall	Symbol Match- Memory Component
		Three Letter Memory- Memory Component
	Picture Match- Correct Delayed Recall	Symbol Match- Memory Component
		Three Letter Memory- Memory Component
Reaction Time	Stop & Go!- Average Time	Symbol Match- Speed Component
		Three Letter Memory- Speed Component
		Eye Tracker- Speed Component
	Picture Match- Average Time	Symbol Match- Speed Component
		Three Letter Memory- Speed Component
		Eye Tracker- Speed Component
	Color Match- Average Time	Symbol Match- Speed Component
		Three Letter Memory- Speed Component
		Eye Tracker- Speed Component
	Design Rotation- Average Time	Symbol Match- Speed Component
		Three Letter Memory- Speed Component
		Eye Tracker- Speed Component

H_1: There will be a correlation between the ImPACT QT-PV constructs and the ImPACT Pediatric constructs assessing memory and reaction time; $\mu_{0=}\mu_1$

3.7.2 Test-Retest Reliability Assessment

Data was analyzed using intra-class correlation coefficients (ICCs) to determine if the ImPACT Pediatric and ImPACT QT-PV assessments demonstrate stability overtime (one week between testing sessions) and consistency in their measurements of neurocognitive function in youth.

3.7.3 Exploratory Research Questions

1. Are there age differences in cognitive performance in youth athletes?

   Data was analyzed using a between-subject ANOVA to determine differences between the age ranges of 6-8 and 9-11 for both the ImPACT QT-PV and the ImPACT Pediatric.

2. Are there sex differences in cognitive performance in youth athletes?

   Data was analyzed using a One-way ANCOVA, controlling for age.

CHAPTER 4

RESULTS

The purpose of this study was to collect and summarize normative data on the ImPACT Pediatric and ImPACT QT-PV among youth athletes. A secondary purpose of this study was to evaluate both the ImPACT Pediatric and ImPACT QT-PV for construct concurrent validity and test-retest reliability. This study also endeavored to explore if the two assessments displayed age or sex differences on the various constructs of the ImPACT Pediatric and ImPACT QT-PV, indicating baseline neurocognitive function differences. The following chapter provides a report of demographic information, as well as findings from statistical analysis for each hypothesis and exploratory question.

4.1 Demographic Data

A total of 202 youth (males=157, 77.3%, females=45, 22.2%) were initially collected for inclusion in the general study analysis. However, after review of the data and removal of 15 outliers, 188 youth (males=147, 78.2%, females=41, 21.8%) remained for data analysis. Of the 188 participants, the mean age of youth was 9.4 ± 1.5 years. The majority of youth fell into three age groups that included 11 years (n=47, 25.0%), 10 years (n=58, 30.9%), and 9 years (n=39, 20.7%) old (Table 4).

Table 4. *Age of Participants Included in Study (n=188)*

Age	Frequency	Valid Percent
6 Years Old	9	4.8
7 Years Old	19	10.1
8 Years Old	16	8.5
9 Years Old	39	20.7
10 Years Old	58	30.9
11Years Old	47	25.0

In regards to personal reporting of ethnicity, the vast majority of youth participants identified as being White (n=138, 73.4%), followed by Black or African American (n=29, 15.4%), and other (n=16, 8.5%) (Table 5).

Table 5. *Ethnicity of Participants Included in Study (n=188)*

Ethnicity	Frequency	Valid Percent
White	138	73.4
Black/African American	29	15.4
Other	16	8.5
Hispanic/Latino	4	2.1
Asian	1	0.5

Most participants conveyed playing more than one sport, however only the self-reported primary sport of participants was recorded for analysis purposes. A total of 8 sports were represented in our sample with the most common sports being basketball (n=120, 63.8%), football (n=42, 22.3%), and karate (n=9, 4.8%) (Table 6).

Table 6. *Sport Participation Breakdown (n=188)*

Sport	Frequency	Valid Percent
Basketball	120	63.8
Football	42	22.3
Karate	9	4.8
Gymnastics	6	3.2
Soccer	6	3.2
Baseball	3	1.6
Softball	1	0.5
Dance	1	0.5

Each participant also conveyed self-reported baseline symptoms at the time of testing on both the ImPACT Pediatric and ImPACT QT-PV. The following is a breakdown of the most commonly reported baseline symptoms on the ImPACT Pediatric assessment: light sensitivity (n=18, 9.6%), more tired than usual (n=16, 8.5%), car sick (n=12, 6.4%), difficulty remembering (n=7, 3.7%), and TV made them feel worse (n=6, 3.2%) (Table 7).

Table 7. *Baseline Symptoms for ImPACT Pediatric (n=188)*

ImPACT Pediatric Baseline Symptoms	Frequency	Percent
Light Sensitivity	18	9.6
More Tired Than Usual	16	8.5
Car Sick	12	6.4
Difficulty Remembering	7	3.7
TV Made Feel Worse	6	3.2
Stomachache	5	2.7
Dizzy	5	2.7
Headache	4	2.1
Noise Sensitivity	4	2.1
Reading Made Feel Worse	3	1.6
Trouble Seeing	1	0.5

The following is a breakdown of the most commonly reported baseline symptoms on the ImPACT QT-PV assessment: headache (n=3, 1.6%), trouble seeing (n=3, 1.6%), stomachache (n=2, 1.1%) and dizzy (n=1, 0.5%) (Table 8).

Table 8. *Baseline Symptoms for ImPACT QT-PV (n=188)*

ImPACT QT-PV Baseline Symptoms	Frequency	Percent
Headache	3	1.6
Trouble Seeing	3	1.6
Stomachache	2	1.1
Dizzy	1	0.5

4.2 Normative Data

A series of descriptive statistics were conducted to assist in providing normative values for youth athletes on both the ImPACT Pediatric constructs and ImPACT QT-PV constructs. Each assessment was analyzed overall, including all 188 participants, for construct mean and standard deviation (SD) values (Tables 9 and 10).

Table 9. *Normative Reference Values Overall for ImPACT Pediatric (n=188)*

ImPACT Pediatric Construct	**Overall Mean (SD)**
Word List Immediate Recall Number Correct	3.70 (1.25)
Design Rotation Average Time	2.05 (0.56)
Design Rotation Number Correct	9.45 (1.00)
Traffic Light Average Time	0.74 (0.13)
Traffic Light Number Correct	9.78 (0.67)
Memory Touch Highest Sequence	5.43 (1.58)
Memory Touch Number Correct	5.47 (2.79)
Memory Touch Sequences Correct	2.03 (1.40)
Picture Match Average Taps	36.76 (6.14)
Picture Match Average Time	33.08 (6.87)
Color Match Average Time	0.96 (0.15)
Color Match Number Correct	8.45 (1.27)
Word List Delayed Recall Number Correct	2.78 (1.53)
Word List Delayed Recognition Number Correct	9.10 (1.17)
Picture Match Correct Delayed Recognition	14.86 (1.47)

Table 10. *Normative Reference Values Overall for ImPACT QT-PV (n=188)*

ImPACT QT-PV Construct	**Overall Mean (SD)**
Symbol Match Correct Visible Average Answer Time	1.45 (0.44)
Symbol Match Number Correct Hidden	4.09 (1.19)
Three Letters-Letters Correct Pass 1	2.39 (0.98)
Three Letters-Letters Correct Pass 2	2.31 (0.98)
Three Letters-Letters Correct Pass 3	2.27 (1.06)
Eye Tracker Rectangular Average Time Correct	0.50 (0.07)
Eye Tracker Figure Eight Average Time Correct	0.53 (0.07)
Eye Tracker Complex Average Time Correct	0.55 (0.06)

The overall normative reference values from the sample were also separated into percentile scores. These scores were discrete individual scores that corresponded with a certain percentile score. The percentiles in analyses included 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 95^{th}. These were selected to show a broad spectrum of ability levels within cognitive performance on memory and reaction time tasks, constituted by various constructs. Some constructs of note on the ImPACT Pediatric included traffic light number correct, memory touch sequences correct, picture match average taps, and design rotation average time. For the traffic light number correct, at the 25th percentile participants already reached the maximum score possible. Conversely with the memory touch sequences correct, at the 25th percentile participants only got one or zero out of five sequences correct. With the picture match average taps, the range of taps was large, with some participants who fell in the 95th percentile taking 20 more taps than those who fell into the 5th percentile. Lastly, the largest span on a reaction time construct was during design rotation average time, with 75% of participant's recording a score of 2.34 seconds or lower, which represents slightly over halfway through the range of recorded times. Table 11 shows a complete list of constructs and percentile scores for the ImPACT Pediatric.

Table 11. *Normative Reference Values Percentile Scores for ImPACT Pediatric (n=188)*

Percentile	**5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**
Word List- Immediate Recall Number Correct	1	2	3	4	5	5	5
Design Rotation- Average Time	1.34	1.43	1.63	1.95	2.34	2.78	3.16
Design Rotation- Number Correct	8	8	9	10	10	10	10
Traffic Light- Average Time	0.57	0.60	0.65	0.72	0.81	0.95	1.01
Traffic Light- Number Correct	9	9	10	10	10	10	10
Memory Touch- Highest Sequence	2.45	3.00	4.00	6.00	7.00	7.00	8.00
Memory Touch- Number Correct	0.45	2.00	4.00	6.00	8.00	9.00	10.00
Memory Touch- Sequences Correct	0	0	1	2	3	4	5
Picture Match- Average Taps	28.30	30.60	32.67	35.33	40.00	46.00	48.55
Picture Match- Average Time	23.09	24.62	28.09	32.38	37.23	43.24	45.48
Color Match- Average Time	0.74	0.80	0.86	0.95	1.06	1.16	1.23
Color Match- Number Correct	6	7	8	9	9	9	9
Word List- Delayed Recall Number Correct	0	0	2	3	4	5	5

Table 11 (cont'd)

Word List- Delayed Recognition Number Correct	7.00	8.00	9.00	9.50	10.00	10.00	10.00
Picture Match- Correct Delayed Recognition	13	13	14	15	16	16	16

Percentile scores were also recorded for the ImPACT QT-PV (Table 12). Similar results were recorded for repeating tasks such as three letters-letters correct and eye tracker average time correct. For the Symbol match number correct hidden, by the 50^{th} percentile the maximum score was reached by some participants. The symbol match correct visible average answer time construct, 75% of participants recorded a time below halfway through the range of scores times recorded.

Table 12. *Normative Reference Values Percentile Scores for ImPACT QT-PV (n=188)*

Percentile	**5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**
Symbol Match- Correct Visible Average Answer Time	0.95	1.02	1.15	1.32	1.68	2.04	2.39
Symbol Match- Number Correct Hidden	1.45	2.00	4.00	5.00	5.00	5.00	5.00
Three Letters- Letters Correct Pass 1	0	1	2	3	3	3	3
Three Letters- Letters Correct Pass 2	0	1	2	3	3	3	3
Three Letters- Letters Correct Pass 3	0	0	2	3	3	3	3
Eye Tracker- Rectangular Average Time Correct	0.40	0.41	0.44	0.50	0.54	0.60	0.63
Eye Tracker- Figure Eight Average Time Correct	0.41	0.44	0.48	0.53	0.57	0.63	0.65
Eye Tracker- Complex Average Time Correct	0.45	0.47	0.50	0.55	0.59	0.64	0.67

Also, separate analyses were performed for each assessment with participants analyzed by sex (male or female), and by age (younger youth 6-8 years or older youth 9-11 years) for their respective means and standard deviations. The normative means on the ImPACT Pediatric indicate that overall males perform better cognitively on memory and reaction time tasks than females (Table 13). Additionally, on the ImPACT Pediatric the resultant mean scores for the two established age group's implied older youth outperformed younger youth on memory and reaction time tasks (Table 14).

Table 13. *Normative Reference Values by Sex for ImPACT Pediatric (n=188)*

ImPACT Pediatric Construct	Male Mean (SD)	Female Mean (SD)
Word List Immediate Recall Number Correct	3.76 (1.22)	3.49 (1.34)
Design Rotation Average Time	1.98 (0.55)	2.32 (0.54)
Design Rotation Number Correct	9.50 (0.99)	9.27 (1.03)
Traffic Light Average Time	0.72 (0.12)	0.83 (0.14)
Traffic Light Number Correct	9.76 (0.74)	9.88 (0.33)
Memory Touch Highest Sequence	5.56 (1.52)	4.95 (1.70)
Memory Touch Number Correct	5.64 (2.71)	4.85 (3.01)
Memory Touch Sequences Correct	2.06 (1.38)	1.90 (1.46)
Picture Match Average Taps	37.01 (5.93)	35.86 (6.82)
Picture Match Average Time	32.95 (6.70)	33.53 (7.54)
Color Match Average Time	0.96 (0.15)	0.99 (0.14)
Color Match Number Correct	8.50 (1.22)	8.27 (1.42)
Word List Delayed Recall Number Correct	2.79 (1.51)	2.73 (1.61)
Word List Delayed Recognition Number Correct	9.13 (1.15)	9.00 (1.25)
Picture Match Correct Delayed Recognition	14.86 (1.50)	14.83 (1.34)

Table 14. *Normative Reference Values by Age Grouping for ImPACT Pediatric (n=188)*

ImPACT Pediatric Construct	Youth Age 6-8 Mean (SD)	Youth Age 9-11 Mean (SD)
Word List Immediate Recall Number Correct	2.82 (1.48)	3.97 (1.04)
Design Rotation Average Time	2.52 (0.63)	1.91 (0.45)
Design Rotation Number Correct	9.02 (1.15)	9.58 (0.91)
Traffic Light Average Time	0.88 (0.13)	0.70 (0.10)
Traffic Light Number Correct	9.82 (0.45)	9.77 (0.73)
Memory Touch Highest Sequence	4.82 (1.50)	5.62 (1.56)
Memory Touch Number Correct	4.55 (2.66)	5.75 (2.78)
Memory Touch Sequences Correct	1.73 (1.30)	2.12 (1.42)
Picture Match Average Taps	37.98 (7.25)	36.39 (5.73)
Picture Match Average Time	37.05 (7.42)	31.87 (6.23)

Table 14 (cont'd)

Color Match Average Time	1.05 (0.15)	0.94 (0.13)
Color Match Number Correct	7.82 (1.99)	8.65 (0.87)
Word List Delayed Recall Number Correct	1.70 (1.71)	3.10 (1.31)
Word List Delayed Recognition Number Correct	8.64 (1.51)	9.24 (1.01)
Picture Match Correct Delayed Recognition	14.73 (1.68)	14.90 (1.40)

On the ImPACT QT-PV, sex results presented more mixed findings, with no clear distinction being drawn as to which sex performed more superior (Table 15). Like the ImPACT Pediatric, the ImPACT QT-PV mean scores separated by age group indicated that older youth perform slightly better than younger youth on memory and reaction time tasks (Table 16).

Table 15. *Normative Reference Values by Sex for ImPACT QT-PV (n=188)*

ImPACT QT-PV Construct	**Male Mean (SD)**	**Female Mean (SD)**
Symbol Match Correct Visible Avg Answer Time	1.45 (0.44)	1.43 (0.42)
Symbol Match Number Correct Hidden	4.16 (1.19)	3.85 (1.17)
Three Letters-Letters Correct Pass 1	2.47 (0.89)	2.12 (1.21)
Three Letters-Letters Correct Pass 2	2.27 (1.00)	2.49 (0.87)
Three Letters-Letters Correct Pass 3	2.24 (1.06)	2.39 (1.05)
Eye Tracker Rectangular Average Time Correct	0.50 (0.07)	0.48 (0.07)
Eye Tracker Figure Eight Average Time Correct	0.53 (0.07)	0.53 (0.08)
Eye Tracker Complex Average Time Correct	0.55 (0.06)	0.55 (0.08)

Table 16. *Normative Reference Values by Age Grouping for ImPACT QT-PV (n=188)*

ImPACT QT-PV Construct	**Youth Age 6-8 Mean (SD)**	**Youth Age 9-11 Mean (SD)**
Symbol Match Correct Visible Avg Answer Time	1.45 (0.46)	1.44 (0.43)
Symbol Match Number Correct Hidden	3.95 (1.20)	4.13 (1.19)
Three Letters-Letters Correct Pass 1	2.14 (1.11)	2.47 (0.92)
Three Letters-Letters Correct Pass 2	2.25 (0.94)	2.33 (0.99)
Three Letters-Letters Correct Pass 3	2.20 (1.07)	2.29 (1.06)
Eye Tracker Rectangular Average Time Correct	0.50 (0.08)	0.50 (0.07)
Eye Tracker Figure Eight Average Time Correct	0.54 (0.08)	0.53 (0.06)
Eye Tracker Complex Average Time Correct	0.57 (.07)	0.54 (0.06)

4.3 Concurrent Validity

H_1: There will be a correlation between the ImPACT QT-PV constructs and the ImPACT Pediatric constructs assessing memory and reaction time; $\mu_{0=}\mu_1$

Concurrent validity was assessed to determine whether memory and reaction time constructs on the ImPACT QT-PV correlated with memory and reaction time constructs on the ImPACT Pediatric. A total of 10 correlations were performed with five assessing memory and reaction time, respectively. Of the 10 correlations performed, none revealed a statistically significant correlation at a p-value of 0.05 (Table 17). However, the correlation between the ImPACT Pediatric construct of color match-average time and the ImPACT QT-PV construct of symbol match-visible average answer time was found to border on significance with a p-value of 0.07. With no statistically significant correlations being found, the hypothesis that the ImPACT QT-PV and ImPACT Pediatric constructs assessing memory and reaction time would be correlated is not supported, and thus rejects validation of the ImPACT QT-PV ($\mu_{0\neq}\mu_1$).

Table 17. *Correlation Analysis Outputs between Modules of Interest (n=188)*

Construct Tested	ImPACT Pediatric	ImPACT QT-PV	Pearson Correlation (*r*) (CI)	Significance (*p*)
Memory	Word List-Immediate Recall	Symbol Match-Number Correct Hidden	-0.10 (-0.25, 0.05)	0.19
	Memory Touch-Number Correct		0.04 (-0.25, 0.43)	0.60
	Word List-Delayed Recall	Three Letters-Letters Correct_Pass1	0.01 (-0.21, 0.25)	0.86
		Three Letters-Letters Correct_Pass2	0.02 (-0.20, 0.26)	0.80
		Three Letters-Letters Correct_Pass3	-0.03 (-0.25, 0.17)	0.70
Reaction Time	Stop & Go!-Average Time	Eye Tracker-Rectangular Average Time	-0.04 (-0.33, 0.20)	0.62
		Eye Tracker-Figure Eight Average Time	0.03 (-0.22, 0.32)	0.72
		Eye Tracker-Complex Average Time	0.12 (-0.04, 0.54)	0.09
	Design Rotation-Average Time	Symbol Match-Visible Average Answer Time	-0.07 (-0.28, 0.09)	0.33
	Color Match-Average Time		-0.13 (-0.09, 0.01)	0.07

4.4 Test-Retest Reliability

H_2: There will be a correlation between the ImPACT QT-PV constructs and the ImPACT Pediatric constructs from assessment time 1 to assessment time 2; $\mu_0 = \mu_1$

Statistical analyses were performed to assess test-retest reliability of both the ImPACT Pediatric and ImPACT QT-PV assessments. Thirty-eight participants were collected solely for these analyses, taking the assessment two times with 7 days between testing sessions. An ICC two-way random, single measure (2,1) model was utilized for reliability evaluation between assessment constructs recorded at time point 1 and time point 2. A total of 15 ICCs were calculated for the ImPACT Pediatric and a total of 9 ICCs were calculated for the ImPACT QT-

PV. With administration of the same test twice, the expected ICC values indicating a high correlation was 0.90. This study's results revealed overall poor reliability for both the ImPACT Pediatric and ImPACT QT-PV assessments. The $ICC_{(2,1)}$ values for the ImPACT Pediatric ranged from 0.12-0.75 (single), with the highest ICC value 0.75 for the construct traffic light average time. The $ICC_{(2,1)}$ values for the ImPACT QT-PV ranged from 0.11-0.69 (single), with the highest ICC value 0.69 for the construct counting average correct. Each of the highest $ICC_{(2,1)}$ values for the two assessments indicated only moderate construct reliability. A full breakdown of $ICC_{(2,1)}$ values can be found in Tables 18 and 19. With only one correlation on the ImPACT Pediatric and no correlations on the ImPACT QT-PV from time point 1 to time point 2 indicating excellent test-retest reliability, the null hypothesis is rejected for both assessments.

Table 18. *Test-Retest Reliability ICC Values for ImPACT Pediatric (n=38)*

ImPACT Pediatric Construct	**ICC**	**Significance (*p*)**	**CI**
Word List Immediate Recall Number Correct	0.20	0.12	-0.13, 0.48
Design Rotation Average Time	0.63	<0.001	0.39, 0.79
Design Rotation Number Correct	0.12	0.23	-0.20, 0.42
Traffic Light Average Time	0.75	<0.001	0.58, 0.86
Traffic Light Number Correct	0.12	0.23	-0.20, 0.42
Memory Touch Highest Sequence	0.49	0.001	0.21, 0.70
Memory Touch Number Correct	0.57	<0.001	0.30, 0.75
Memory Touch Sequences Correct	0.48	0.001	0.19, 0.69
Picture Match Average Taps	0.53	<0.001	0.25, 0.72
Picture Match Average Time	0.47	0.001	0.18, 0.68
Color Match Average Time	0.58	<0.001	0.58, 0.32
Color Match Number Correct	0.60	<0.001	0.36, 0.77
Word List Delayed Recall Number Correct	0.13	0.22	-0.20, 0.43
Word List Delayed Recognition Number Correct	0.43	0.004	0.13, 0.65
Picture Match Correct Delayed Recognition	0.70	<0.001	0.49, 0.83

Table 19. *Test-Retest Reliability ICC Values for ImPACT QT-PV (n=38)*

ImPACT QT-PV Construct	**ICC**	**Significance (*p*)**	**CI**
Symbol Match Correct Visible Avg Answer Time	0.51	<0.001	0.24, 0.71
Symbol Match Number Correct Hidden	0.23	0.08	-0.09, 0.51
Counting Average Correct	0.69	<0.001	0.48, 0.83
Three Letters-Letters Correct Pass 1	0.18	0.14	-0.15, 0.47
Three Letters-Letters Correct Pass 2	0.11	0.26	-0.22, 0.41
Three Letters-Letters Correct Pass 3	0.31	0.03	-0.01, 0.57
Eye Tracker Rectangular Average Time Correct	0.47	0.001	0.18, 0.69
Eye Tracker Figure Eight Average Time Correct	0.58	<0.001	0.32, 0.76
Eye Tracker Complex Average Time Correct	0.63	<0.001	0.39, 0.79

Response stability for each construct was assessed using the standard error of measurement (SEM). Additionally, the minimal detectable change (MDC), which is the smallest amount of change that a measure can detect, was computed. The SEM and MDC for each construct of both the ImPACT Pediatric and ImPACT QT-PV are displayed below in Tables 20 and 21.

Table 20. *Test-Retest Reliability SEM & MDC Values for ImPACT Pediatric (n=38)*

ImPACT Pediatric Construct	**SEM**	**MDC**
Word List Immediate Recall Number Correct	0.98	2.72
Design Rotation Average Time	0.37	1.03
Design Rotation Number Correct	0.64	1.77
Traffic Light Average Time	0.06	0.18
Traffic Light Number Correct	0.29	0.81
Memory Touch Highest Sequence	0.90	2.50
Memory Touch Number Correct	1.53	4.24
Memory Touch Sequences Correct	0.85	2.35
Picture Match Average Taps	4.23	11.74
Picture Match Average Time	6.01	16.65
Color Match Average Time	0.09	0.25
Color Match Number Correct	0.72	1.99
Word List Delayed Recall Number Correct	1.30	3.59
Word List Delayed Recognition Number Correct	0.94	2.61
Picture Match Correct Delayed Recognition	0.87	2.42

Table 21. *Test-Retest Reliability SEM & MDC Values for ImPACT QT-PV (n=38)*

ImPACT QT-PV Construct	SEM	MDC
Symbol Match Correct Visible Avg Answer Time	0.45	1.26
Symbol Match Number Correct Hidden	1.38	3.82
Counting Average Correct	1.55	4.29
Three Letters-Letters Correct Pass 1	1.01	2.80
Three Letters-Letters Correct Pass 2	0.98	2.71
Three Letters-Letters Correct Pass 3	0.92	2.56
Eye Tracker Rectangular Average Time Correct	0.05	0.13
Eye Tracker Figure Eight Average Time Correct	0.04	0.11
Eye Tracker Complex Average Time Correct	0.03	0.07

4.5 Age Differences in Cognitive Performance

EQ1: Are there age differences (i.e., 6-8 years, 9-11 years) in cognitive performance?

Cognitive Performance was assessed between the two age groups of our study, younger youth 6-8 years and older youth 9-11 years old. ANOVAs were used for statistical analysis to identify any significant differences on memory and reaction time constructs. On the ImPACT Pediatric, of the six constructs assessed, five including the word list immediate recall number correct, design rotation average time, traffic light average time, color match average time, and word list delayed recall number correct, were found to be statistically significant between the two age groups at a p-value of 0.05. On each of the five constructs, older youth scored better than younger youth indicating an age effect on performance for both memory and reaction time components. Table 22 outlines all the memory and reaction time constructs with their corresponding F-statistics and p-values.

Table 22. *ANOVA Outputs for ImPACT Pediatric Constructs (n=188)*

ImPACT Pediatric Construct	F	Significance (*p*)
Word List Immediate Recall Number Correct	11.08	<0.001
Design Rotation Average Time	13.06	<0.001
Traffic Light Average Time	21.92	<0.001
Memory Touch Number Correct	1.74	0.13
Color Match Average Time	6.40	<0.001
Word List Delayed Recall Number Correct	8.68	<0.001

Eight constructs from the ImPACT QT-PV were also evaluated for age differences, however none proved to be statistically significant at a p-value of 0.05 (Table 23).

Table 23. *ANOVA Outputs for ImPACT QT-PV Constructs (n=188)*

ImPACT QT-PV Construct	F	Significance (*p*)
Symbol Match Correct Visible Avg Answer Time	1.79	0.12
Symbol Match Number Correct Hidden	0.73	0.60
Three Letters-Letters Correct Pass 1	1.68	0.14
Three Letters-Letters Correct Pass 2	2.09	0.07
Three Letters-Letters Correct Pass 3	0.29	0.92
Eye Tracker Rectangular Average Time Correct	1.26	0.29
Eye Tracker Figure Eight Average Time Correct	1.89	0.10
Eye Tracker Complex Average Time Correct	1.94	0.09

Additional analyses were performed in the form of ANCOVAs controlling for sex. This was done to neutralize the effect of sex when evaluating the constructs for age differences. The results from the ANCOVA analyses did not significantly vary from the results of the ANOVAs previously performed. Therefore, the results of the ANCOVAs were not included in this section, as they only reiterated the results of the ANOVAs. This suggests that sex did not significantly alter performance when comparing age groups.

4.6 Sex Differences in Cognitive Performance

EQ2: Are there sex differences in cognitive performance in youth athlete's age 6-11 years old?

Additionally, cognitive performance on memory and reaction time constructs were evaluated for significant sex differences within the ImPACT Pediatric. ANCOVAs, controlling for age as a covariate, were performed using the same selected constructs from the ANOVA analyses. Analysis revealed only one statistically different construct, traffic light average time (p=0.004), with males recording faster reaction times compared to females (Table 24). Group means for the two sexes are available for reference in Table 13.

Table 24. *ANCOVA Outputs for ImPACT Pediatric Constructs (n=188)*

ImPACT Pediatric Construct	**F**	**Significance**
Word List Immediate Recall Number Correct	0.06	0.81
Design Rotation Average Time	3.50	0.06
Traffic Light Average Time	8.74	0.004
Memory Touch Number Correct	0.90	0.34
Color Match Average Time	0.12	0.74
Word List Delayed Recall Number Correct	1.41	0.24

On the ImPACT QT-PV, out of all the ANCOVAs performed, none revealed to be statistically significant for a sex difference (Table 25). Group means for the two sexes are available for reference in Table 15.

Table 25. *ANCOVA Outputs for ImPACT QT-PV Constructs (n=188)*

ImPACT QT-PV Construct	**F**	**Significance**
Symbol Match Correct Visible Avg Answer Time	0.01	0.91
Symbol Match Number Correct Hidden	1.32	0.25
Three Letters-Letters Correct Pass 1	3.47	0.06
Three Letters-Letters Correct Pass 2	1.56	0.21
Three Letters-Letters Correct Pass 3	0.71	0.40
Eye Tracker Rectangular Average Time Correct	2.87	0.09
Eye Tracker Figure Eight Average Time Correct	0.002	0.97
Eye Tracker Complex Average Time Correct	0.002	0.97

CHAPTER 5

DISCUSSION

This study was primarily conducted to collect and summarize normative data on the ImPACT Pediatric and ImPACT QT-PV among youth athletes. Additionally, construct concurrent validity and test-retest reliability were evaluated for the two assessments as a secondary purpose of this study. Moreover, exploratory questions concerning age and sex differences on the assessment constructs of the ImPACT Pediatric and ImPACT QT-PV were examined. This chapter endeavors to expand on results from the statistical analysis presented in chapter 4 and attempts to provide rational explaining the findings.

5.1 General Summary of Results

The outcomes from the current study complimented and added to the existing knowledge base concerning the ImPACT Pediatric and ImPACT QT-PV assessments. Results indicated, that in its present form, the ImPACT QT-PV is not a valid measure of memory and reaction time in youth athletes. Additionally, neither the ImPACT QT-PV nor ImPACT Pediatric displayed adequate test-retest reliability to deem them as stable measures of cognition over time.

When separate analyses were performed to determine if age affected neurocognitive outcomes on the ImPACT Pediatric and ImPACT QT-PV, it was revealed that as age increased so did cognitive performance on memory and reaction time tasks within the ImPACT Pediatric. Analyses evaluating neurocognitive performance were also conducted based on sex and controlling for age. These results indicated only one reaction time construct to be statistically different for the ImPACT Pediatric. In this case, male participants displayed a faster reaction time than female participants. However, overall sex was not found to affect performance in youth 6-11 years of age on either the ImPACT Pediatric or ImPACT QT-PV assessments.

5.2 Normative Values for ImPACT Pediatric and ImPACT QT-PV

An objective of the current study was to help provide baseline normative values for both the ImPACT Pediatric and ImPACT QT-PV that would add to the current body of knowledge for each assessment. This study is one of the first to collect normative data for youth using the ImPACT QT-PV, therefore there is no similar baseline data for comparisons to be made. However, associations can be made with the ImPACT Pediatric test and the only other previous study that also reported normative values. When comparing the overall means obtained in this study with the ImPACT Company data, each constructs mean was very similar (Table 26). The largest difference between reaction time components was on picture match average time, where the ImPACT Company mean (34.91) was slower than the mean recorded from this study (33.08) by nearly 2 seconds. On a memory construct, the largest difference was 1.5 points on word list delayed recognition. Again, the mean from the ImPACT Company revealed poorer performance than what was displayed in this study. However, neither of these findings are overly concerning as the means from both data are very close.

Table 26. *Overall Normative Reference Values for ImPACT Pediatric*

ImPACT Pediatric Construct	**ImPACT Company Mean (SD)**	**Current Study Mean (SD)**
Word List Immediate Recall Number Correct	3.18 (1.30)	3.70 (1.25)
Design Rotation Average Time	2.71 (0.95)	2.05 (0.56)
Design Rotation Number Correct	8.74 (2.29)	9.45 (1.00)
Traffic Light Average Time	0.97 (0.09)	0.74 (0.13)
Traffic Light Number Correct	9.81 (0.48)	9.78 (0.67)
Memory Touch Highest Sequence	5.70 (1.26)	5.43 (1.58)
Memory Touch Number Correct	6.27 (2.25)	5.47 (2.79)
Memory Touch Sequences Correct	2.54 (1.17)	2.03 (1.40)
Picture Match Average Taps	36.48 (5.09)	36.76 (6.14)
Picture Match Average Time	34.91 (6.79)	33.08 (6.87)
Color Match Average Time	1.02 (0.17)	0.96 (0.15)
Color Match Number Correct	8.37 (1.44)	8.45 (1.27)
Word List Delayed Recall Number Correct	2.33 (1.36)	2.78 (1.53)
Word List Delayed Recognition Number Correct	7.53 (1.29)	9.10 (1.17)

In comparing the means between the same data, comparisons can also be evaluated based on sex (Tables 27 and 28). While our study found that overall males slightly outperformed females on most of the memory and reaction time tasks, the ImPACT Company had contrasting results. Only the constructs of word list immediate recall number correct and word list delayed recall number correct demonstrated better performance by males. The rest of the means for each construct were not statistically different between male and female athletes. The data for males and females was very consistent, demonstrating no difference between the sexes on constructs for their means and standard deviations. Therefore, additional analysis of differing normative values based on sex is needed due to the disparities found between the current study and the ImPACT Company.

Table 27. *Male Normative Reference Values for ImPACT Pediatric*

ImPACT Pediatric Construct	**ImPACT Company Mean (SD)**	**Current Study Mean (SD)**
Word List Immediate Recall Number Correct	3.22 (1.33)	3.76 (1.22)
Design Rotation Average Time	2.71 (0.95)	1.98 (0.55)
Design Rotation Number Correct	8.74 (2.29)	9.50 (0.99)
Traffic Light Average Time	0.97 (0.09)	0.72 (0.12)
Traffic Light Number Correct	9.81 (0.48)	9.76 (0.74)
Memory Touch Highest Sequence	5.70 (1.26)	5.56 (1.52)
Memory Touch Number Correct	6.27 (2.25)	5.64 (2.71)
Memory Touch Sequences Correct	2.54 (1.17)	2.06 (1.38)
Picture Match Average Taps	36.47 (5.14)	37.01 (5.93)
Picture Match Average Time	34.91 (6.79)	32.95 (6.70)
Color Match Average Time	1.02 (0.17)	0.96 (0.15)
Color Match Number Correct	8.37 (1.44)	8.50 (1.22)
Word List Delayed Recall Number Correct	2.34 (1.39)	2.79 (1.51)
Word List Delayed Recognition Number Correct	7.53 (1.29)	9.13 (1.15)

Table 28. *Female Normative Reference Values for ImPACT Pediatric*

ImPACT Pediatric Construct	**ImPACT Company Mean (SD)**	**Current Study Mean (SD)**
Word List Immediate Recall Number Correct	3.10 (1.25)	3.49 (1.34)
Design Rotation Average Time	2.71 (0.95)	2.32 (0.54)
Design Rotation Number Correct	8.74 (2.29)	9.27 (1.03)
Traffic Light Average Time	0.97 (0.09)	0.83 (0.14)
Traffic Light Number Correct	9.81 (0.48)	9.88 (0.33)
Memory Touch Highest Sequence	5.70 (1.26)	4.95 (1.70)
Memory Touch Number Correct	6.27 (2.25)	4.85 (3.01)
Memory Touch Sequences Correct	2.54 (1.17)	1.90 (1.46)
Picture Match Average Taps	36.49 (5.01)	35.86 (6.82)
Picture Match Average Time	34.91 (6.79)	33.53 (7.54)
Color Match Average Time	1.02 (0.17)	0.99 (0.14)
Color Match Number Correct	8.37 (1.44)	8.27 (1.42)
Word List Delayed Recall Number Correct	2.30 (1.29)	2.73 (1.61)
Word List Delayed Recognition Number Correct	7.53 (1.29)	9.00 (1.25)

Comparison between the two data sets can also be conducted based on age range (Tables 29 and 30). When separated into an older age group 9-11 years and a younger age group 6-8 years, the current study found significant differences in neurocognitive performance. The older youth outperformed the younger youth on all constructs except traffic light number correct, where younger youths mean scores were slightly better. The reason for the younger youths better performance on the one construct is unknown, however with knowledge of the lack of reliability associated with the assessment as reported in the results section, this could contribute to misrepresented findings. The findings of the current study closely align with the mean findings of the ImPACT Company where they also reported older youth outperformed younger youth on every construct.

Table 29. *Youth Age 6-8 Normative Reference Values for ImPACT Pediatric*

ImPACT Pediatric Construct	**ImPACT Company Mean (SD)**	**Current Study Mean (SD)**
Word List Immediate Recall Number Correct	2.68 (1.37)	2.82 (1.48)
Design Rotation Average Time	2.95 (1.01)	2.52 (0.63)
Design Rotation Number Correct	8.59 (2.35)	9.02 (1.15)
Traffic Light Average Time	0.98 (0.07)	0.88 (0.13)
Traffic Light Number Correct	9.74 (0.56)	9.82 (0.45)
Memory Touch Highest Sequence	5.24 (1.34)	4.82 (1.50)
Memory Touch Number Correct	5.32 (2.33)	4.55 (2.66)
Memory Touch Sequences Correct	2.07 (1.18)	1.73 (1.30)
Picture Match Average Taps	36.94 (5.05)	37.98 (7.25)
Picture Match Average Time	37.67 (7.47)	37.05 (7.42)
Color Match Average Time	1.10 (0.19)	1.05 (0.15)
Color Match Number Correct	8.09 (1.94)	7.82 (1.99)
Word List Delayed Recall Number Correct	1.87 (1.35)	1.70 (1.71)
Word List Delayed Recognition Number Correct	8.60 (1.43)	8.64 (1.51)

Table 30. *Youth Age 9-11 Normative Reference Values for ImPACT Pediatric*

ImPACT Pediatric Construct	**ImPACT Company Mean (SD)**	**Current Study Mean (SD)**
Word List Immediate Recall Number Correct	3.78 (1.19)	3.97 (1.04)
Design Rotation Average Time	2.44 (0.84)	1.91 (0.45)
Design Rotation Number Correct	8.90 (2.23)	9.58 (0.91)
Traffic Light Average Time	0.95 (0.11)	0.70 (0.10)
Traffic Light Number Correct	9.88 (0.39)	9.77 (0.73)
Memory Touch Highest Sequence	6.21 (1.16)	5.62 (1.56)
Memory Touch Number Correct	7.30 (2.17)	5.75 (2.78)
Memory Touch Sequences Correct	3.05 (1.15)	2.12 (1.42)
Picture Match Average Taps	35.50 (5.18)	36.39 (5.73)
Picture Match Average Time	31.96 (6.05)	31.87 (6.23)
Color Match Average Time	0.94 (0.15)	0.94 (0.13)
Color Match Number Correct	8.66 (0.93)	8.65 (0.87)
Word List Delayed Recall Number Correct	2.92 (1.37)	3.10 (1.31)
Word List Delayed Recognition Number Correct	9.11 (1.14)	9.24 (1.01)

Overall the findings from this study closely align with the data provided by the ImPACT Company. Therefore, the data gather using the ImPACT Pediatric assessment in this study simply add to the current established normative values. Additionally, with no current normative values established for the ImPACT QT-PV, the collected values in this study may be a start in establishing normal values overall, as well as based on sex and age for this youth concussion assessment tool. However, caution should be warranted in use and interpretation of these findings due to the lack of reliability of the ImPACT Pediatric found in this study.

5.3 ImPACT Pediatric and ImPACT QT-PV Construct Concurrent Validity

Validity analysis of the constructs contained within the ImPACT QT-PV was a main focus of the current study. To date there has not been a study that has evaluated the validity of the ImPACT QT-PV. Conversely, the ImPACT Pediatric has already undergone multiple forms of validity evaluation including construct, face, and concurrent validity (Lovell, 2015). In each of these evaluations the ImPACT Pediatric has produced acceptable results, rendering itself a valid measure of cognition in youth 5-12 years of age (Lovell, 2015). In lieu of these findings, the current study aimed to assess the concurrent validity of the ImPACT QT-PV with the validated measure of the ImPACT Pediatric. The ImPACT QT-PV would seem very similar on the surface to the ImPACT Pediatric, as the two assessments measure the same cognitive functions (i.e. memory and reaction time), require an iPad for administration, and were designed for use in the same age range. However, the results from this study did not indicate a correlation between the memory and reaction time constructs contained within the ImPACT QT-PV and ImPACT Pediatric assessments. From the 10 correlations performed, the *r*-values ranged from -0.13 – 0.12, with none being statistically significant at a p-value of 0.05. The overwhelming synthesis of the analysis indicated that the two concussion assessments were not related; therefore the ImPACT QT-PV can be interpreted as an invalid concussion measure in its current state.

With this being said, there is an obvious inherent issue with the analyses performed within this study. The ImPACT QT-PV is still undergoing development and, as such, the developers have not yet determined the formulas for transfiguring the raw data, used in this study, into composite or factor scores. Composite or factor scores may allow for better comparison of data between assessments as they transpose data onto a standard scale. The raw data from both assessments, used for comparison in this study, posed a problem due to the varying scales of each construct used in the correlation analyses. This did not allow for accurate comparison between the memory and reaction time constructs as the scores were based on different scales. Therefore, re-evaluation of the concurrent validity between the ImPACT QT-PV and ImPACT Pediatric should be conducted after the ImPACT QT-PV constructs can be transfigured into composite or factor scores. After which, correlations should be performed between the composites of each assessment.

5.4 Test-Retest Reliability

This study was one of the first to evaluate the test-retest reliability of the ImPACT Pediatric, and the first to evaluate the test-retest reliability of the ImPACT QT-PV. ICCs were evaluated using the two-way random, single measure model. With the same assessments being administered to participants at two time points one week apart, ICC values were expected to be very high, reaching excellent status. Both of the assessments in this study demonstrated unsatisfactory reliability overall. The ICC values ranged from 0.12-0.75 and 0.11-0.69, demonstrating poor to excellent reliability for the ImPACT Pediatric and poor to good reliability for the ImPACT QT-PV, respectively.

The ImPACT Pediatric results from this study vary from the ImPACT Pediatric results reported in the ImPACT Pediatric: Administration and Interpretation Manual. In the ImPACT

Pediatric manual, the test-retest reliability ICC values ranged from 0.46-0.89 demonstrating fair to excellent reliability. These results are from an ongoing, unpublished study, which consisted of 142 youth 5-12 years of age, composed primarily of males (72%) where the second test was administered sometime between one week to one month after the first test (Lovell, 2015). It is unclear why this unpublished study demonstrated higher reliability values than the current study. However, with very little information given about the unpublished study from the ImPACT manual, it is possible that there were differences that caused the evident disparity. These differences could include a better testing environment, more one-on-one attention, an older participant population tested, or some other variable(s) that led to the higher reliability values. The current study attempted to control for these variables, but fell short in certain areas. In the current study, participants were tested indoors, in a quiet room located within a school library. Although this environment was mostly free of distractions, there was some noise from other students using the library and activities taking place in the library. Also, the test administrator tested two participants simultaneously, which could create a distraction for each participant, as well as lessen complete focus on each participant individually. Once the study in the ImPACT manual is published, deeper examination of its methods and parameters should be scrutinized.

There is a lack of studies evaluating youth concussion assessments, creating a gap in literature, as well as making comparisons difficult. Therefore, the next best available option for comparison lies with construct-similar assessments created for older populations. In the case of the ImPACT Pediatric, the ImPACT assessment, which was created by the same company and was used in the development of its youth counterpart, can be used in reliability comparison as a substitute for better suited and age appropriate assessments. The test-retest reliability of the ImPACT assessment has been examined in multiple studies. In a study by Womble, Reynolds, Schatz, and Kontos (2016), the test-retest reliability of the ImPACT was evaluated in youth ice hockey players 11-18 years of age with the second test administered anywhere from 45-days to 1-year after the first. The resultant reliability values ranged from 0.35-0.75, indicating poor to excellent reliability (Womble et al., 2016). A similar study evaluating the ImPACT assessment in high school and collegiate athletes found ICCs ranging from 0.29-0.71 on the test composite scores, indicating poor to good reliability, with the second test was administered 1 to 3 days after the first (Register-Mihalik et al., 2012). Each of these studies assessing the reliability of the ImPACT assessment produced similar findings to the results of this study. Reliability is thought to be essential for consistency and stability in measurement, therefore without high reliability the assessments usefulness and accuracy is called into question. Therefore, further examination into factors that may contribute to poor consistency, as well as the test constructs, needs to be further examined. Without determination and correction of the measurement instability, clinicians should be cautious in interpretation of the neurocognitive outputs from the ImPACT, ImPACT Pediatric, and ImPACT QT-PV for their athletes. This further increases the importance of using a multifaceted approach during clinical evaluation of an athlete at both baseline and post-concussion. By using multiple assessments for evaluation, not one single measure is being solely relied upon in concussion assessment and management.

5.5 Age Differences Based on ImPACT Pediatric and ImPACT QT-PV Constructs

To date there has been limited evaluation of age as a factor on neurocognitive outcomes, particularly in youth populations. For both the ImPACT Pediatric and ImPACT QT-PV, this study is one of the first to explore age differences in the memory and reaction time constructs. The age range for each assessment included youth 6-11 years of age, which was then divided into two age groups including a younger age group (i.e. 6-8 years) and an older age group (i.e. 9-

11 years). This division of the study's age range was chosen for the purpose of comparing outcomes between the younger portion and older portion of the youth sample. The age range was split directly down the middle, creating two groups composed of three ages. With age, especially in younger individuals, having a profound impact on development, the six years of difference in the age range established for the two assessments was considered a large span, which could produce varying performance differences. It was demonstrated in our results that older youth performed better on memory and reaction time constructs when compared to younger youth athletes on the ImPACT Pediatric. These results are consistent with other previous studies evaluating age differences in middle school, high school, and collegiate athletes. A study by Sharma et al. (2014) examined the effect of age on paper and pencil neurocognitive test performance in adolescent's age 12-17 years. They found that test performance increased as a function of age across all age groups (Sharma et al., 2014). Comparably, another study examined normative data of ImPACT composite scores in athletes 13-18 years old, with age differences again being demonstrated. Older participants (16-18 years) performed better on the composites of processing and reaction time than younger participants (13-14 years) (Iverson, Lovell, & Collins, 2003). These findings suggest that as young individuals age, their brains continue to develop and maturate, thus improving cognitive performance.

With few studies evaluating performance differences as a function of age in youth populations, further comparison can be made with older populations where developmental differences have been studied. High school athletes were assessed in a study based on age for neuropsychological performance differences. In this study performance was found to progressively increase by grade level, across the four high school grades. There were significant differences in information processing speed, attention, and motor dexterity between 9th grade and

11th grade and 9th grade and 12th grade athletes, with older individuals performing better (Hunt & Ferrara, 2009). Kail and Ferrer (2007) conducted a study on developmental changes in youth, and found that visual motor speed had greater improvements in children than in adolescence. In a study by Kail (1991), youth 8-10 years demonstrated slower processing speeds compared to youth 12-13 years. Additionally, it has been found that as processing speed increases, working memory, as well as the neurocognitive components of problem solving and reasoning also improve (Kail, 2007). Faster processing speeds, along with greater working memory, problem solving, and reasoning ability, allow for more optimal performance on tasks by older youth compared to younger youth. If this developmental trend in cognitive function can be predicated to youth younger, then these findings may suggest different expectations and normative values be used for younger versus older youth samples.

Another study examined differences on neurocognitive test performance between high school and collegiate athletes, with age again being found to effect performance (Register-Mihalik et al., 2012). On the ImPACT assessment, college athletes demonstrated faster processing speed than their high school counterparts. Additionally, college athletes performed better on the ImPACT assessment than high school athletes at each of the three testing sessions (Register-Mihalik et al., 2012). These studies at the high school and collegiate level provide further support to the conclusion that as age increases, there is synonymous cognitive growth and processing proliferations. Thus age should be taken into consideration when comparing outcome scores to normative data post-concussion, due to the significant differences displayed in this study between our age groups on memory and reaction time components within the ImPACT Pediatric. Also, as part of a best practice approach, it is particularly important to administer baseline assessments to all athletes for the most accurate pre and post comparison. Likewise, re-administration of baseline assessments each year should be completed, specifically in the youth population, due to rapid brain development and meaningful improvements in cognition. However, it should be noted that age differences seen on the ImPACT Pediatric could be misrepresentative, as the assessment was not found to demonstrate reliability in the current study. Without acceptable validity and reliability values for an assessment, re-administration on a yearly basis would be useless as results cannot be confidently trusted.

5.6 Sex Differences Based on ImPACT Pediatric and ImPACT QT-PV Constructs

Sex-based differences in neurocognitive performance outcomes have been widely studied in high school and collegiate athlete populations at both baseline and post-concussion. However, to-date limited research involving youth has examined sex-based neurocognitive performance. The current study is one of the first to evaluate youth concussion assessments for male and female baseline performance differences. The memory and reaction time constructs of the ImPACT Pediatric and ImPACT QT-PV assessments were examined for sex differences. Our results demonstrated only one statistically significant construct for the ImPACT Pediatric assessment, with the construct being a measure of reaction time. No statistically significant constructs from the ImPACT QT-PV were found. The significant construct within the ImPACT Pediatric assessment was traffic light average time, with males exhibiting faster reaction times than their female counterparts. No other reaction time constructs, or any memory constructs, were found to be statistically significant between the sexes.

These results of youth 6-11 years old are not comparable to other studies involving youth's baseline scores, as sex has not been considered in other studies using this younger population. However, there have been studies conducted comparing male and female athletes in high school and collegiate settings demonstrating mixed results. In a study by Brooks, Iverson, Atkins, Zafonte, and Berkner (2016), sex differences in 13-18 year old athletes were evaluated during baseline concussion testing using the ImPACT assessment. They found that females demonstrated significantly superior performance than males on the visual-motor composite score. However, no differences were found between male and female scores on verbal memory, visual memory, impulse control, or reaction time composites (Brooks et al., 2016). In another study, high school and collegiate athletes demonstrated sex differences on the ImPACT assessment. Females performed statistically better on verbal memory and processing speed measures compared to males, however there were no differences found on visual memory or reaction time scores (Covassin, Elbin, Larson, & Kontos, 2012). Covassin, Schatz, and Swanik (2007) conducted a study solely evaluating collegiate athletes with respect to sex differences on the ImPACT assessment. The results from this study showed no significant differences on any of the composite scores with regard to sex (Covassin, Schatz, & Swanik, 2007). Assimilating the above studies results, it remains unclear if male and female athletes do differ in performance on baseline neuropsychological assessments, and if so, on which composites. However, in comparing our significant reaction time finding to the available literature in older populations, no other studies replicated this finding during baseline testing. There are a few possible explanations for our dissimilar result. First, this study involved a youth population that has not been adequately studied in terms of sex differences; therefore this could be a normal finding at this age range, 6-11 years. Second, our sample was decidedly skewed with a greater number of males compared to female participants. Third, from our previous discussion of age differences, it was shown that older youth, 9-11 years old, displayed significantly faster reaction times than younger youth, 6-8 years old. Therefore, by having far more male participants in our sample who fell into the older age group of 9-11 years compared to females, this could have caused a misrepresentation of our results. However, all of these points are speculative, therefore, replication studies with more balanced samples are needed for more accurate determination of sex differences.

5.7 Youth Concussion Policy

The results from the current study should be used to inform legislation related to youth SRC. Currently, there is not a required policy or standard practice for youth organizations, emergency departments, and other institutions to follow in management of a SRC for youth athletes. This causes a discrepancy in the tools used, if any, by organizations to determine if a concussion has been sustained, even though for youth there are very few available. With the selection and implementation of a youth concussion protocol requiring the use of specific youth concussion assessment tools, a greater database of information can be established and the current tools in place can be better refined. This would be more beneficial than the continual creation of additional youth concussion assessment tools. With the implementation of a standard protocol, a standard of practice will be created for implementation across all organizations, which will remove the guesswork for organizations unsure of the procedure to follow. Also, this may require the addition of an appropriate health care provider on staff at youth sport organizations to administer concussion assessments and help inform on concussion treatment and management. In return, youth sports will become a safer environment in which youth can engage, and apprehensive parents may be more willing to allow their children to participate with the added safety measures in place.

5.8 Limitations

The current study was not without limitations, which will be discussed in this section. There was an evident disparity in ages represented. Using our pre-established age groupings, there was a greater number of athletes in the older youth (i.e. 9-11 years) category (n=144, 76.6%) versus the younger youth (i.e. 6-8 years) category (n=44, 23.4%). There were also a disproportionate number of males (n=147, 78.2%) compared to females (n=41, 21.8%), providing us with a male dominated sample. The age and sex skewedness of our participant sample may have rendered inaccurate depictions of what differences may actually be evident with both the ImPACT Pediatric and ImPACT QT-PV assessments. Additionally, the sports composing our sample, though varied, were primarily represented by basketball (n=120, 63.8%) and football (n=42, 22.3%). This heavy skew in sports participation by our sample does not allow for generalizability of our findings to all sports. A more equal distribution among sports participation would allow generalizability of the assessments to other sports and further analysis comparisons that are based on sport. It should also be noted that testing sessions were completed both indoors and outdoors. The outdoor testing environments were not always in a noise-controlled area, which could have led to distraction from the test session. Additionally, although most of the outdoor testing sessions were done under a portable pop-up tent providing a shaded environment for testing, a few tests were completed in the exposed sun. With the tests completed outside without shade, the participants complained of a glare on the iPad screen, which hindered their optimal test-taking ability. The glare caused participants to miss certain aspects involving components lighting up on the screen, such as circles that flash during the ImPACT QT-PV memory touch construct. This environmental hindrance produced an inaccurate depiction of the youth's ability level and ultimate score. Additionally, it should be noted as a limitation that some youth acknowledged previously taking other neuropsychological concussion assessments, although this was not a question recorded by the researcher. With exposure to other assessments, a practice effect may have been evident, affecting score outcomes and rendering inflated results.

5.9 Future Research

The results from this study were useful in progressing the present knowledge surrounding the ImPACT Pediatric and ImPACT QT-PV youth concussion assessments. However, there were areas identified where re-examination and further research is warranted. In regard to the limitations acknowledged in this study, replication studies are needed that contain a more equally distributed sample in terms of age, sex, and sport participation to supplement the findings of this study. Additionally, the testing environment should be considered when administering an iPad assessment outside, and appropriate pre-cautions should be taken to prevent direct sun-exposure during testing. Also, continued research is needed to add to the collection of normative values for both the ImPACT Pediatric and ImPACT QT-PV assessments to aid in the development of normative baseline reference values for youth 6-11 years of age.

Once, composite scores are available for the ImPACT QT-PV, concurrent validity between the ImPACT QT-PV and ImPACT Pediatric should be reassessed. Research investigating the test-retest reliability of both the ImPACT QT-PV and ImPACT Pediatric should also be conducted to determine if there are influential factors causing variability between testing sessions, rendering the assessments unreliable. Additionally, both assessments can be given to adult populations to evaluate if the assessments are reliable in this older population. Adults should not only perform better on these assessments, but they should also display more consistent results. The roles age and cognitive development play in neurocognitive performance should be further examined. Likewise, sex should be explored further, with a more equivalent sample, to see if it does predispose certain sexes to better performance on different tasks, as is seen in older populations.

Future research should also expand on the findings and reach of the present study. Personal factors such as ADHD/ADD and diagnosed learning disabilities should be explored to determine if they affect performance on the ImPACT Pediatric or ImPACT QT-PV assessments. Also, history of concussion should be examined for its impact on neurocognitive performance during baseline testing. Lastly, post-concussion evaluation should be done using the ImPACT Pediatric and ImPACT QT-PV to discern the accuracy of these youth concussion assessments in the field.

There were a couple observations from this study that suggest recommendations for revision of the ImPACT QT-PV assessment. The first recommendation would be to install a practice section before each module to assist in ensuring the youth understand the instructions for completing each task. This would allow the test administrator the opportunity to correct incorrect performance before the module is being scored during the actual task completion. The second recommendation for this assessment would be to include a pause button. A pause button would be useful to aid in correcting incorrect performance during a task once it has already been begun. This would prevent a youth from continuing to complete a task incorrectly from misunderstanding instructions. Also, a pause button would be helpful if a youth gets overzealous or accidentally hit the "start test" button before the test administrator has reviewed instructions with them. In this case, the youth do not understand how to complete a task and begin completing it incorrectly, therefore scoring poorly and inaccurately depicting their ability level. The above recommendations could improve the quality of the ImPACT QT-PV assessment and the accuracy of the outcomes produced.

5.10 Conclusion

In conclusion, the findings of this study were relevant and useful for knowledge advancement. The present study made a supple addition to the normative data for both the ImPACT Pediatric and ImPACT QT-PV assessment. Concurrent validity analysis of the ImPACT QT-PV with the ImPACT Pediatric rendered the ImPACT QT-PV an invalid measure of cognitive function in youth. Additionally, both the ImPACT Pediatric and ImPACT QT-PV demonstrated a lack of reliability and stability between testing sessions one-week apart. Age was identified as a compounding factor in neurocognitive performance, with performance improving as a function of increasing age. However, sex overall was not found to affect neurocognitive performance on memory or reaction time tasks in this study's youth population, which varies from literature involving older populations.

With the aforementioned factors in mind, clinicians should practice caution in their use and interpretation of the ImPACT Pediatric and ImPACT QT-PV results. Likewise, when using either of the above assessments for concussion evaluation, clinicians should be aware of potential differences in baseline scores based on the youth athletes age. Baseline testing should re-occur each year to capture potential gains in cognitive performance. As is the recommended standard, no single concussion assessment tool should be used by itself as the sole predictor of concussion. A multifaceted approach, using multiple assessment tools measuring a variety of components affected by concussion, should always be implemented at baseline and poet-concussion in clinical practice. Future research should continue examination of the ImPACT Pediatric and ImPACT QT-PV youth concussion assessments, as their research remains in the early stages and further development and standardization are needed with each assessment.

APPENDIX

APPENDIX

INSTITUTIONAL REVIEW BOARD (IRB) APPPROVAL FORM

MICHIGAN STATE UNIVERSITY

Renewal Application Approval

September 14, 2016

To: Tracey Covassin
105 IM Sports Circle

Re: **IRB# 15-998** Category: EXPEDITED 4, 7
Renewal Approval Date: September 14, 2016
Project Expiration Date: September 13, 2017

Title: To examine the reliability and validity of the ImPACT Quick Test (QT) and ImPACT Pediatric Quick Test (QT-Ped)

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

This renewal the sample size being increased to 500.

The review by the committee has found that your renewal is consistent with the continued protection of 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.

Sincerely,

Ashir Kumar, M.D.
BIRB Chair

MICHIGAN STATE UNIVERSITY Founded 1855

Office of Regulatory Affairs
Human Research Protection Programs

Biomedical & Health Institutional Review Board (BIRB)

Community Research Institutional Review Board (CRIRB)

Social Science Behavioral/Education Institutional Review Board (SIRB)

Olds Hall
408 West Circle Drive, #207
East Lansing, MI 48824
(517) 355-2180
Fax: (517) 432-4503
Email: irb@msu.edu
www.hrpp.msu.edu

REFERENCES

REFERENCES

Anthoine, E., Moret, L., Regnault, A., Sbille, V., & Hardouin, J.B. (2014). Sample size used to validate a scale: a review of publications on newly-developed patient reported outcomes measures. *Health and Quality of Life Outcomes*, 12(176).

Baillargeon, A., Lassonde, M., Leclerc, S., & Ellemberg, D. (2012). Neuropsychological and neurophysiological assessment of sport concussion in children, adolescents, and adults. *Brain Injury*, 26(3) 211-220. Doi:10.3109/02699052.2012.654590

Bakhos L.L., Lockhart, G.R., Myers, R., & Linakis, J.G. (2010). Emergency department visits for concussion in young child athletes. *Pediatrics*, 126, e550-e556.

Barnes, B. C., Cooper, L., Kirkendall, D. T., McDermott, T. P., Jordan, B. D., & Garrett, W. E., Jr. (1998). Concussion history in elite male and female soccer players. *American Journal of Sports Medicine*, 26, 433–438.

Baugh, C.M., Kroshus, E., Bourlas, A.P., & Perry, K.I. (2014). Requiring Athletes to Acknowledge Receipt of Concussion-Related Information and Responsibility to Report Symptoms: A Study of the Prevalence, Variation, and Possible Improvements. *Journal of Law, Medicine & Ethics*, 42(3), 297-313. doi:10.1111/jlme.12147

Boden, B., kirkendall, D., & Garrett Jr., W.E. (1998). Concussion incidence in elite college soccer players. *American Journal of Sports Medicine*, 26(2), 238-241.

Brooks, B.L., Iverson, G.L., Atkins, J.E., Zafonte, R., & Berkner, P.D. (2016). Sex Differences and Self-Reported Attention Problems During Baseline Concussion Testing. *Applied Neuropsychology*, 5, 119-126.

Broglio, S.P., Cantu, R.C., Gioia, G.A., Guskiewicz, K.M., Kutcher, J., Palm, M., & Valovich McLeod, T.C. (2014). National Athletic Trainers' Association Position Statement: Management of Sport Concussion. *Journal of Athletic Training*, 49(2), 245-265.

Broglio, S.P. & Puetz, T.W. (2008). The Effect of Sport Concussion on Neurocognitive Funciton, Self-Report Symptoms and Postural Control. *Sports Medicine*, 38(1), 53-67.

Broshek, D.K., Kaushik, T., Freeman, J.R., Erlanger, D., Webbe, F., & Barth, J.T. (2005). Sex differnces in outcome following sports-related concussion. *Journal of Neurosurgery*, 102(5), 856-863.

Cantu, R.C. (2016). Dysautoregulation/Second –Impact Syndrome with Recurrent Athletic Head Injury. *World Neurosurgery*, 95. 601-602.

Cantu, R.C., Guskiewicz, K., & Register-Mihalik, J.K. (2010). A retrospective clinical analysis of moderate to severe athletic concussions. *Physical Medicine & Rehabilitation*, 2(12), 1088-1093.

Child-SCAT3: Sport Concussion Assessment Tool. (2013). *British Journal of Sports Medicine*, 47, 263.

Coghlin, C.J., Myles, B.D., & Howitt, S.D. (2009). The ability of parents to accurately report concussion occurrence in their bantam-aged minor hockey league children. *Journal of the Canadian Chiropractic Association*, 53(4), 233-250.

Concannon, L.G., & Herring, S.A. (2014). Preventable Tragedies. Consensus statement, 47(5), 250-8.

Covassin, T., Elbin, R.J., Bleecker, A., Lipchik, A., & Kontos, A. (2013). Are There Differences in Neurocognitive Function and Symptoms Between Male and Female Soccer Players After Concussions? *American Journal of Sports Medicine*, 41(12), 2890-2895.

Covassin, T., Elbin, R.J., Harris, W., Parker, T., & Kontos, A. (2012). The Role of Age and Sex in Symptoms, Neurocognitive Performance, and Postural Stability in Athletes After Concussion. *American Journal of Sports Medicine*, 40(6), 1303-1312.

Covassin, T., Elbin, R.J., Larson, E., & Kontos, A.P. (2012). Sex and Age Differences in Depression and Sports-Related Concussion Neurocognitive Performance and Symptoms. *Clinical Journal of Sports Medicine*, 22, 98-104.

Covassin, T., Schatz, P., & Swanik, C.B. (2007). Sex Differences in Neuropsychological Function and Post-Concussion Symptoms of Concussed Collegiate Athletes. *Neurosurgery*, 61, 345-351.

Covassin, T., Stearne, D., Elbin III, R. (2008). Concussion History and Postconcussion Neurocognitive Performance and Symptoms in Collegiate Athletes. *Journal of Athletic Training*, 43(2), 119-124.

Covassin, T., Swanik, C.B., & Sachs, M.L. (2007). Sex Differences in baseline neuropsychological function and post-concussion symptoms of concussed collegiate athletes. *Neurosurgery*, 61, 345-351.

Covassin, T., Swanik, C.B., Sachs, M.L., Kendrick, Z., Schatz, P., Zilllmer, E., Kaminaris, C. (2006). Sex Differences in baseline neuropsychological function and concussion symptoms of collegiate athletes. *British Journal of Sports Medicine*, 40(11), 923-927.

Crowe, L., Collie, A., Hearps, S., Dooley, J., Clausen, H., Maddocks, D., McCrory, P., Davis, G., & Anderson, V. (2016). Cognitive and physical symptoms of concussive injury in children: a detailed longitudinal recovery study. *British Journal of Sports Medicine*, 50, 311-316.

De Beaumont, L., Brisson, B., Lassonde, M., Jolicoeur, P. (2007). Long-term electrophysiological changes in athletes with a history of multiple concussions. *Brain Injury*. 21(6), 631-644.

De Beaumont, L., Mongeon, D., Tremblay, S., Messier, J., Prince, F., Leclerc, S., Lassonde, M., & Theoret, H. (2011). Persistent Motor System Abnormalities in Formerly Concussed Athletes. *Journal of Athletic Training*, 46(3), 234-240.

Dekosky, S.T., Ikonomovic, M.D., & Gandy, S. (2010). Traumatic Brain Injury- Football, Warefare, and Long-Term Effects. *New England Journal of Medicine*, 363, 1293-1296.

Deroche, T., Stephan, Y., Woodman, T., & Le Scanff, C. (2012). Psychological Mediators of the Sport Injury-Perceived Risk Relationship. *Risk Analysis: An International Journal*, 32(1), 113-121. doi:10.1111/j.1539-6924.2011.01646.x

Dompier, T.P., Kerr, Z.Y., Marshall, S.W., Hainline, B., Snook, E.M., Hayden, R., & Simon, J.E. (2015). Incidence of concussion during practice and games in youth, high school, and collegiate American football players. *JAMA Pediatrics*, 169(7), 659-665.

Dziemianowicz, M.S., Kirschen, M.P., Pukenas, B.A., Laudano, E., Balcer, L.J., & Galetta, S.L. (2012). Sports-related concussion testing. *Current Neurology and Neuroscience Reports*, 12(5), 547-559.

Echemendia, R.J., Putukian, M., Mackin, R.S., Julian, L., & Shoss, N. (2011) Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. *Clinical Journal of Sports Medicine*, 11(1), 23-31.

Eckner, J.T., Kutcher, J.S., Richardson, J.K. (2010). Pilot Evaluation of a Novel Clinical Test of Reaction Time in National Collegiate Athletic Association Division I Football Players. *Journal of Athletic Training,* 45(4), 327-332.

Edwards, J.C. & Bodle, J.D. (2014). Causes and Consequences of Sports Concussion. *Journal of Law, Medicine, & Ethics*, 42(2), 128-132. doi:10.1111/jlme.12126

Erlanger, D.M., Kutner, K., Barth, J., & Barnes, R. (1999). The neuropsychology of sports-related head injury: From dementia pugilistica to post-concussion syndrome. *The Clinical Neuropsychologist*, 13, 193–210.

Frommer, L.J., Gurka, K.K., Cross, K.M., Ingersoll, C.D., Comstock, R.D., & Saliba, S.A. (2011). Sex Differences in Concussion Symptoms of High School Athletes. *Journal of Athletic Training*, 46(1), 76-84.

Fry, J.D., Greenop, K., & Schutte, E. (2010). The Effects of Fatigue and the Post-Concussion Syndrome on Executive Functioning in Traumatic Brain Injury and Healthy Comparisons. *Journal of Interdisciplinary Health Sciences*, 15(1), 146-153.

Gagnon, I., Galli, C., Friedman, D., Grilli, L., & Iverson, G. L. (2009). Active Rehabilitation for Children Who Are Slow to Recover Following Sport-Related Concussion. *Brain Injury*, 23(12), 956-964. doi:10.3109/02699050903373477

Galetta, K.M., Morganroth, J., Moehringer, N., Mueller, B., Hasanaj, L., Webb, N., Civitano, C., Cardone, D.A., Silverio, A., Galetta, S. L., & Balcer, L.J. (2015). Adding Vision to Concussion Testing: A Prospective Study of Sideline Testing in Youth and Collegiate Athletes. *Journal of Neuro-Ophthamology*, 00, 1-7.

Gessel, L., Fields,S., Collins, C., & Comstock, R. (2007). Concussions among United States High School and Collegiate Athletes. *Journal of Athletic Training*, 42(4), 495-503.

Giva, C.C. and Hovda, D.A. (2001). The Neurometabolic Cascade of Concussion. *Journal of Athletic Training*, 36(3), 228-235.

Gourley, M.M., McLeod, T.C.V., & Bay, R.C. (2010). Awareness and recognition of concussion by youth athletes and their parents. *Athletic Training & Sports Health Care: The Journal for the Practicing Clinician*, 2(5), 208-218.

Henry, L.C., Tremblay, S., Boulanger, Y., Ellemberg, D., & Lassonde, M. (2010). Neurometabolic Changes in the Acute Phase after Sports Concussions Correlate with Symptom Severity. *Journal of Neurotrauma*, 27, 65-76.

Hunt, T.N. & Ferrara, M.S. (2009). Age-Related Differences in Neuropsychological Testing Among High School Athletes. *Journal of Athletic Training*, 44(4), 405-09.

Iverson, G.L., Brooks, B.L., Collins, M.W., & Lovell, M.R. (2006). Tracking neuropsychological recovery following concussion in sport. *Brain Injury*, 20(3), 245-252.

Iverson, G.L., Gaetz, M., Lovell, M.R., & Collins, M.W. (2004). Cumulative effects of concussion in amateur athletes. *Brain Injury*, 8(5), 433-443.

Iverson, G.L., Lovell, M.R., & Collins, M.W. (2003). Immediate Post-Concussion Assessment and Cognitive Test (ImPACT): Normative Data. Version 2.0. http://www.impacttest.com/ArticlesPage_images/Articles_Docs/7ImPACTNormativeDataversion%202.pdf.

Kail, R.V. (1991). Developmental Change in Speed of Processing During Childhood and Adolescence. *Psychological Bulletin*, 109(3), 490-501.

Kail, R.V. (2007). Longitudinal Evidence that Increases in Processing Speed and Working Memory Enhance Children's Reasoning. *Psychological Science*, 18(4), 312-313.

Kail, R.V. & Ferrer, E. (2007). Processing Speed in Childhood and Adolescence: Longitudinal Models for Examining Developmental Change. *Child Development*, 78(6), 1760-1770.

Kerr, Z.Y., Roos, K.G., Djoko, A., Dalton, S.L., Broglio, S.P., Marshall, S.W., & Dompier, T.P. (2016a). Epidemiologic Measures for Quantifying the Incidence of Concussion in National Collegiate Athletic Association Sports. *Journal of Athletic Training*, doi:10.4085/1062-6050-51.6.05

Kerr, Z.Y., Zuckerman, S.L., Wasserman, E.B., Covassin, T., Djoko, A., & Dompier, T.P. (2016b). Concussion Symptoms and Return to Play Time in Youth, High School, and College American Football Athletes. *JAMA Pediatrics*, doi:10.1001/jamapediatrics.2016.0073

Kontos, A.P., Elbin, R.J., Fazio-Sumrock V.C., Burkhart, S., Swindell, H., Maroon, J., & Collins, M.W. (2013). Incidence of sports-related concussion among youth football players aged 8-12 years. *The Journal of Pediatrics*, 163(3), 717-720.

Kontos, A.P., Elbin, R.J., Schatz, P., Covassin, T., Henry, L., Pardini, J., & Collins, M. (2012). A Revised Factor Structure for the Post-Concussion Symptom Scale: Baseline and Postconcussion Factors. *The American Journal of Sports Medicine*, 40(10), 2375-2384.

Langois, J. A. Rutland-Brown, W., & Wald, M. M. (2006). The Epidemiology and Impact of Traumatic Brain Injury: A Brief Overview. *Journal of Head Trauma Rehabilitation*, 21, 375–378.

Lear, A.M. & Hoang, M.H. (2012). Sports concussion: A return-to-play guide. *Journal of Family Practice*, 61(6), 323-328.

Lee, Y.M., Odom, M.J., Zuckerman, S.L., Solomon, G.S., & Sills, A.K. (2013). Does age affect symptom recovery after sports-related concussion? A study of high school and collegiate athletes. *Journal of Neurosurgery: Pediatrics*, 12(6), 537-544.

Lee, A.J. & Lin, W.H. (2007). The influence of gender and somatotype on single-leg upright standing postural stability in children. *Journal of Applied Biomechanics*, 23(3), 173-179.

Lovell, M. (2015). Impact Pediatric: Administration and Interpretation Manual.

Macciocchi, S.N., Barth, J.T., Alves, W., Rimel, R.W., & Jane, J.A. (1996). Neuropsychological functioning and recovery after mild head injury in collegiate athletes. *Neurosurgery*, 39(3), 510-514.

Mayers, L.B., Redick, T.S., Chiffriller, S.H., Simone, A.N., & Terraforte, K.R. (2011). Working memory capacity among collegiate student athletes: Effects of sport-related head contacts, cocussions, and working memory demands. *Journal of clinical & Experimental Neuropsychology*, 33(5), 532-537. doi:10.1080/13803395.2010.535506

Mayo Clinic Staff. (2014). Risk factors. Retrieved March 24, 2016 from http://www.mayoclinic.org/diseases-conditions/concussion/basics/risk-factors/con-20019272

McClincy, M.P., Lovell, M.R., Pardini, J., Collins, M.W., & Spore, M.K. (2006). Recovery from Sports Concussion in High School and Collegiate Athletes. *Brain Injury*, 20(1), 33-39.

McCrea, M., Hammeke, T., Olsen, G., Leo, P., & Guskiewicz, K. (2004). Unreported concussion in high school football players: Implications for prevention. *Clinical Journal of Sports Medicine*, 14(1), 13-17.

McCrory, P., Collie, A., Anderson, V., & Davis, G. (2004). Can we manage sport related concussion in children the same as in adults? *British Journal of Sports Medicine*, 38(5), 516-519.

McCrory, P., Meeuwisse, W.H., Aubry, M., Cantu, R.C., Dvorak, J., Echemendia, R.J., Engebretsen, L., Johnston, K., Kutcher, J.S., Raftery, M., Sills, A., Benson, B.W., Davis, G.A., Ellenbogen, R., Guskiewicz, K.M., Herring, S.A., Iverson, G.L., Jordan, B.D., Kissick, J., & McCrea, M. (2013). Consensus Statement on Concussion in Sport: The 4th International Conference on Concussion in Sport, Zurich, November 2012. *Journal of Athletic Training*, 48(4), 554-575.

McGuire, C. & McCambridge, T. (2011). Concussion in the Young Athlete: Diagnosis, Management, and Prevention. *Contemporary Pediatrics*, 28(5), 30-46.

McKeever, C.K. & Schatz, P. (2003). Current Issues in the Identification, Assessment, and Management of Concussions in Sports-Related Injuries. *Applied Neuropsychology*, 10(1), 4-11.

McLeod. T.C.V. & Leach C. (2012). Psychometric Properties of Self-Report Concussion Scales and Checklists. *Journal of Athletic Training*, 47(2), 221-223.

Moore, M.T., Murphy, B., Seramur, D., Lovell, M.R. (2015). Validity and Reliability of Pediatric ImPACT in Five to Twelve Year Olds. *Journal of Athletic Training*, 50(6 Supplement), S-27.

Moser, R. (2007). The Growing Health Concern of Sports Concussion: The New Psychology Practice Frontier. *Professional Psychology: Research and Practice*, 38(6), 699-704. doi:10.1037/0735-7028.38.6.699

Neumann, L. (2011). Raising awareness of the severity of concussions. *The Sport Journal*, 14(1), 1-14.

Notebaert A.J. & Guskiewicz K.M. (2005). Current Trends in Athletic Training Practice for Concussion Assessment and Management. *Journal of Athletic Training*, 40(4), 320-325.

Parsons, T.D., Notebaert, A.J., Shields, E.W., & Guskiewicz, K.M. (2009). Application of Reliable Change Indices to Computerized Neuropsychological Measures of Concussion. *International Journal of Neuroscience*, 119, 492-507. doi:10.1080/00207450802330876

Pellman, E.J., Viano, D.C., Tucker, A.M., Casson, I.R., and Waeckerle, J.F. (2003). Concussion in Professional Football: Reconstruction of Game Impacts and Injuries. *Neurosurgery*, 53(4), 799-814.

Piland, S.G., Ferrara, M.S., Macciocchi, S.N., Broglio, S.P., Gould, T.E. (2010). Investigation of Baseline Self-Report Concussion Symptom Scores. *Journal of Athletic Training*, 45(3), 273-278.

Powell, J.W. & Barber-Foss, K. (1999). Traumatic brain injury in high school athletes. *Journal of the American Medical Association*, 282(10), 958-963.

Quatman-Yates, C., Hugentobler, J., Ammon, R., Mwase, N., Kurowski, B., & Myer, G.D. (2014). The Utility of the Balance Error Scoring System for Mild Brain Injury Assessments in Children and Adolescents. *The Physician and Sportsmedicine*, 42(3), 32-38.

Register-Mihalik, J.K., Guskiewicz, K.M., McLeod, T.C., Linnan, L.A., Mueller, F.O., & Marshall, S.W. (2013). Knowledge, attitude, and concussion-reporting behaviors among high school athletes: A preliminary study. *Journal of Athletic Training*. 48(5), 645-653.

Register-Mahalik, J.K., Kontos, D.L., Guskiewicz, K.M., Mihalik, J.P., Conder, R., & Shields, E.W. (2012). Age-Related Differences and Reliability on Computerized and Paper-and-Pencil Neurocognitive Assessment Batteries. *Journal of Athletic Training*, 47(3), 297-305.

Rosenbaum, A.M. & Arnett, P.A. (2010). The development of a survey to examine knowledge about and attitudes toward concussion in high-school students. *Journal of Clinical & Experimental Neuropsychology*, 32(1), 44-55.

Ruchinskas, R., Francis, J., & Barth, J.T. (1997). Mild head injury in sports. *Applied Neuropsychology*, 4, 43–49.

Sander, L. (2010). Colleges Struggle to Protect Athletes From Concussion and Its Aftermath. *Chronicle of Higher Education*, 57(6), A1-A10.

Sarmiento, K., Mitchko, J., Klein, C., & Wong, S. (2010). Evaluation of the Centers for Disease Control and Prevention's Concussion Initiative for High School Coaches: "Heads Up: Concussion in High School Sports". *Journal of School Health*, 80(3), 112-118. doi:10.1111/j.1746-1561.2010.00491.x

Seifert, T.D. (2013). Sports Concussion and Associated Post-Traumatic Headache. *Headache: The Journal of Head & Face Pain*, 53(5), 726-736. doi:10.1111/head.12087

Sharma, V.K., Subramanian, S.K., A.V., R.S., SR.B., & S.V. (2014). Study of Effect of Age and

Gender Related Differences on Common Paper and Pencil Neurocognitive Tests in Adolescents. *Journal of Clinical and Diagnostic Research*, 8(11), BC05–BC10.

Snedden, T.R. (2013). Concept analysis of concussion. *Journal For Specialists In Pediatric Nursing*, 18(3), 211-220. doi:10.1111/jspn.12038

Straus, L.B. (2015). Computerized Neurocognitive Testing: Important Role in Concussion Evaluation, Return to Play Decision. Retrieved from http://www.momsteam.com/impact/computerized-neuropsychological-testing-has-important-role-in-concussion-evaluation-return-play

Tierney, R.T., Higgins, M., Caswell, S.V., et al. (2008). Sex differences in head acceleration during heading while wearing soccer headgear. *Journal of Athletic Training*, 43(6),578-584.

Tripp, D.A., Ebel-Lam, A., Stanish, W., Brewer, B.W., & Birchard, J. (2011). Fear of Reinjury, Negative Affect, and Catastrophizing Predicting Return to Sport in Recreational Athletes with Anterior Cruciate Ligament Injuries at 1Year Postsurgery. *Sport, Exercise, and Performance Psychology*, 1(S), 38-48. doi:10.1037/2157.3905.1.S.38

Weber, M. & Edwards, M.G. (2010). The effect of brain injury terminology on university athletes' expected outcome from injury, familiarity, and actual symptom report. *Brain Injury*, 24(11), 1364-1371.

Womble, M.N., Reynolds, E., Schatz, P., Shah, K.M., & Kontos, A.P. (2016). Test-Retest Reliability of Computerized Neurocognitive Testing in Youth Ice Hockey Players. *Archives of Clinical Neuropsychology*, 31, 305-312.

Zimmer, A., Piecora, K., Schuster, D., & Webbe, F. (2013). Sport and Team Differences on Baseline Measures of Sport-Related Concussion. *Journal of Athletic Training*, 48(5), 659-667.

Zuckerman, S.L., Apple, R.P., Odom, M.J, Lee, Y.M., Solomon, G.S., Sills, A.K. (2014). Effect of sex on symptoms and return to baseline in sports-related concussion. *Journal of Neurosurgery: Pediatrics*, 13(1), 72-81.

Zuckerman, S.L., Lee, Y.M., Odom, M.J., Solomon, G.S., Forbes, J.A., & Sills, A.K. (2012). Recovery from sports-related concussion: Days to return to neurocognitive baseline in adolescents versus young adults. *Surgical Neurology International*, 3, 130. http://doi.org.proxy1.cl.msu.edu/10.4103/2152-7806.102945

Zuckerman, S.L., Kerr, Z.Y., Yengo-Kahn, A., Wasserman, E., Covassin, T., & Solomon, G.S. (2015). Epidemiology of Sports-Related Concussion in NCAA Athletes From 2009-2010 to 2013-2014: Incidence, Recurrence, and Mechanisms. *American Journal of Sports Medicine*, 43(11), 2654-2662.