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Identifying the Effect of Preexisting Conditions on Low Neurocognitive Scores and Symptom Reporting of School-Age Athletes in Baseline Testing for Concussion Management

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IDENTIFYING THE EFFECT OF PREEXISTING CONDITIONS ON LOW NEUROCOGNITIVE SCORES AND SYMPTOM REPORTING OF SCHOOL-AGE ATHLETES IN BASELINE TESTING FOR CONCUSSION MANAGEMENT

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DISSERTATION APPROVAL

This is to certify that the thesis presented to us by Jessica Corrigan on the 11 day of January 2018, in partial fulfillment of the requirements for the degree of Doctor of Psychology, has been examined and is acceptable in both scholarship and literary quality.

COMMITTEE MEMBERS' SIGNATURES

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Abstract

The purpose of this study was to investigate risk factors that are associated with low baseline concussion test scores by examining a range of modifiers such as previous concussion and pre-existing childhood disorders such as LD, ADHD, or mood disorder (depression/anxiety) in middle school age children. This study utilized a between-subjects research design. Participants included de-identified archival data of male and female student athletes, ages 10-14 years old that participated in preseason testing at a small private concussion center located in suburban central New Jersey between 2006 and 2016. Data were obtained using retrospective computerized baseline neuropsychological testing and symptoms reporting data obtained from the ImPACT. Children with a previous diagnosis of Attention Deficit-Hyperactivity Disorder (ADHD) or a learning disability performed significantly lower on most neurocognitive measures compared with children without ADHD or a learning disability. In contrast, there was no difference in neurocognitive scores in children with a previous resolved concussion or pre-existing psychiatric condition (i.e., depression or anxiety), compared with children who had not endured a previous concussion, or with no history of depression or anxiety. Children who reported more symptoms at baseline scored lower on neurocognitive measures, and children with either pre-existing ADHD or psychiatric condition reported more symptoms at baseline. These results converge with current research on concussion and extends it to the 10-14 age range. An important finding of this study was the importance that baseline symptoms play, either independently or interdependently of pre-existing conditions, on initial neurocognitive testing. It also highlights the fact that, despite the current guidelines discouraging routine baseline testing in younger populations due to their changing brains, there may be utility for baseline testing in special populations, given the reduced applicability of norms to these individuals.

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Chapter One: Introduction

Statement of the Problem

Concussion

Concussions are a public health issue that continue to garner the attention of legislators, physicians, the media, researchers, parents, and educators because of their widespread impact on many groups of people such as athletes, children, and military members. A concussion is generally considered to be a subset of traumatic brain injury which results from a direct insult to the head, through acceleration or deacceleration (whiplash), or rotation (McCrory et al., 2012, 2017). Over the past two decades, there has been a surge of interest and increased awareness about the identification, diagnosis, and treatment of concussion (McCrea, 2017).

At the 5th International Conference on Concussion in Sport held in Berlin, *The Consensus Statement on Concussion in Sport* defined a sports-related concussion (SRC) as "a traumatic brain injury, induced by biomechanical forces" (McCrory et al., 2017). Characteristics of a concussion include: acute onset and temporary impairment of neurologic function that typically resolves on its own; disruptions in neuropathology, a "functional disturbance rather than a structural injury"; a set of symptoms which may or may not involve loss of consciousness, and "no abnormality on standard structural neuroimaging studies" (McCrory et al., 2012, 2017). Symptoms of concussion include a collection of physical, cognitive, emotional, and sleep disturbances which often include headache, nausea, fatigue, light and sound sensitivity, vertigo, irritability, emotional lability, difficulty remembering, difficulty concentrating, drowsiness, and word-finding problems (Harmon et al, 2013, McCrory et al., 2017). Although these symptoms are commonly associated with the effects of concussion or a mild traumatic brain injury (mTBI), they are nonspecific because they may overlap, coincide, or interfere with many other health conditions such as mood disorders, neurological problems, and learning or developmental disabilities. This likely has to do with the reason why it has taken so long for concussions to emerge as a public concern with both clinicians and laypersons.

Research

Most sports concussion research has focused on high school and college level athletes. Recent data from the Centers for Disease Control and Prevention reveals that rates of TBI related ED visits has increased for all groups from the period of 2001-2001 through 2009-2010 (CDC, 2016), which is likely due to increased awareness and recognition regarding concussion. Bakhos et al. (2010) conducted a study which examined the emergency department (ED) visits for concussions in the U.S, examining two different pediatric age groups, youth ranging from age 8 to 13 and adolescents, ages 14 to 19 years. Between 2001 and 2005, children ages 8-19 years had approximately 502,000 ED visits for concussion. Younger children, ages 8-13 years, accounted for about 35% of the visits, about half of which were sports related. About half of the sports related concussions in the younger children were sustained during an organized team sport. However, Jinguji, Krabak, and Satchell (2011) pointed out that data regarding the prevalence and epidemiology of concussions in high school age children is at best an estimate, and that even less is known about the epidemiology of concussion in middle-school age and younger children (McCrory et al., 2012, 2017). Many concussions go underreported for a variety of reasons, such as lack of awareness, underestimating the severity of an injury, and the concern surrounding being withheld from competition (McCrea et al., 2004). Experts have identified the fact that certain sports, such as football, ice hockey, basketball, cheerleading, soccer, wrestling, and lacrosse place young athletes at higher likelihood of concussion (McCrory et al., 2012). Thus, it was implicated that the number of emergency department visits of younger children from concussions warranted further research of sports related concussions in youths. Furthermore, research has documented that children with a history of concussion, or a pre-existing diagnosis such as learning disability, attention-deficit/hyperactivity, and mood disorder are more at-risk than the general population for sustaining a concussion (McCrory et al., 2009).

Relevance

The widespread use of neurocognitive testing for the management of sports concussion was first introduced at the University of Virginia in 1989 (Barth, 1989), when baseline assessment (pre-injury) and post-injury testing was utilized to track performance and recovery. Baseline testing purports to gain a short snapshot of the neurocognitive processes of an athlete that are most vulnerable to concussion, such as verbal and visual memory, attention, processing speed, and reaction speed. Baseline testing gained popularity in the 1990s when many National Football League (NFL) teams implemented the practice following a number of head injuries involving famous athletes, and the National Hockey League soon followed suit with mandated baseline neuropsychological testing (Lovell and Collins, 2002; Lovell et al, 2004). Baseline testing formerly consisted of paper-and-pencil measures, and eventually computerized batteries became widespread in use for their brevity, cost effectiveness, and psychometric properties, such as the ability to have multiple test versions for reevaluations in a short time (Lovell and Collins, 2002; Cernich et al., 2007). Currently, computerized measures are popular, as well as hybrid approaches which combine a computerized measure with paper-and-pencil tasks. Baseline testing has been developed and fine-tuned in recent years to consist of brief screening tools that are often computerized and take less than one hour to complete (Lovell and Collins, 2002). One of the most widely used and researched computerized tools is the Immediate Post-Concussion

Assessment and Cognitive Testing, which is the only FDA-cleared computerized concussion tool (Lovell, 2006; ImPACT, 2017).

As concussion awareness continues to gain momentum and recognition both globally and locally, more attention has been given to concussion management amongst the pediatric population. After professional sports teams began to recognize the usefulness of neuropsychological measures for pre-and post-injuries, this practice began to trickle down to collegiate sports as well as high school athletics. Many states have passed legislation regarding concussion education and management to raise awareness and introduce guidelines for children playing those sports which pose greater risks for head injury (Centers for Disease Control and Prevention, 2015). Moreover, as baseline testing has become standard practice in concussion management, more schools have adopted assessment tools such as the ImPACT for pre-injury screenings. Recently, pediatric versions of computerized concussion assessments have been released, such as the ImPACT Pediatric (ImPACT, 2017) and the Child-SCAT3, which demonstrates the widespread use of these tests as well as its shift to include youth groups. However, the clinical utility of computerized tests in children remains unclear (Davis et al., 2017), has generated a lot of discussion, and continues to spur research amongst experts in the field.

Several modifying factors have been associated with the prevalence of sustaining a concussion and the possible subsequent occurrence of post-concussion syndrome. A modifier is defined as a variable that may influence the factor that is being measured. Modifying factors in concussion include a previous concussion as well as pre-existing conditions such as attention-deficit/hyperactivity disorder (ADHD), learning disability (LD), mood disorders (anxiety/depression), migraine, and sleep dysfunction (McCrory et al., 2009; McCrory, 2012). It is important that these modifiers be identified in concussion cases so that these individuals can be appropriately managed in terms of return to play (RTP) and return to learn decisions. In fact, in many cases premorbid factors are a better predictor of Post-Concussion Syndrome (PCS) than the severity of the actual head injury (McClean et al., 2009). The importance of modifiers has already been demonstrated in routine baseline administrations for concussion screening because these factors may indeed influence the neurocognitive scores of a young athlete in the absence of a concussion (Zuckerman et al, 2013). For example, Schatz et al. (2012) highlighted the idea the that ImPACT baseline scores that are flagged invalid by the testing program may be due to the variability within subtests that naturally occurs in subpopulations of child and teenage athletes with a pre-existing condition. Adolescents with a pre-existing condition were deliberately excluded from normative data collection of adolescents, as were baseline scores that were deemed invalid by the ImPACT test (Henry and Sandel, 2015). No study to date has taken a close examination at the factors that are involved in a young child athlete achieving a statistically low baseline score.

The previous Consensus recommended that children who sustain a concussion be assessed by trained neuropsychologists who understand the interpretation of testing data, especially with children who are diagnosed with learning disorders (LD) and/or Attention Deficit/Hyperactivity (ADHD) disorders (McCrory et al., 2012). Moreover, the expert panel encouraged the concept that children do not return to play or school until they are completely symptom free. Thus, they may require a longer period to recover, compared with adults. Although there is limited research on young athletes, extant research has documented unique and slower recovery trajectories for high school athletes in comparison with college-aged and professional athletes (McCrory et al., 2009, 2012). In contrast, the most recent Consensus statement (McCrory et al., 2017) highlights that the extant literature does not have sufficient information on child-specific domains to determine if children with a sports related concussion should be managed differently from adults. One recent study by Brooks et al. (2013) found that adolescent athletes who had sustained at least two previous concussions did not demonstrate any worse performance on the ImPACT neurocognitive battery at baseline, compared with adolescent athletes who did not have any prior concussions, although they endorsed a higher number of baseline symptoms. The adolescents in this sample had no pre-existing conditions such as LD or ADHD. Understanding the unique challenges and differences that the pediatric population encounters is important in concussion management in terms of diagnosis, treatment, and recovery, and affects return to activity and return to school decisions. This was acknowledged by the Zurich panel during the 3rd Consensus in Zurich, because the expert panel called for more research in "pediatric injury and management systems" (McCrory et al., 2009), and pediatrics became a larger focus of the following Consensus.

Need for Study

Looking precisely at the variables that play a role in children and adolescents who obtain low baseline scores is the next step in understanding baseline testing with special populations. Importantly, many baseline tests that are considered invalid are deemed so because of low scores and variability, which is often characteristic of certain pediatric populations, such as those with attentional deficits or learning disabilities (Schatz et al., 2012). The purpose of this study was to investigate the risk factors that are associated with low baseline scores by examining a range of modifiers such as previous concussion and pre-existing childhood disorders such as LD, ADHD, or mood disorder (depression/anxiety) in middle school age children. To date, no study has focused solely on the factors that play into low baseline scores while focusing on a young population. It was hypothesized that children who achieve statistically low neurocognitive baseline testing scores will be more likely to have a pre-existing condition such as a history of concussion, ADHD, LD, or psychiatric disorder (anxiety/depression), and exhibit more symptoms at baseline, compared with a child with no prior conditions. This study explored the relationship between previous concussions and pre-existing childhood disorders such as LD, ADHD, psychiatric condition (anxiety and/or depression) and statistically low baseline test scores in school age children. This was accomplished by using retrospective computerized neuropsychological testing and symptoms reporting data obtained from the ImPACT test.

Hypothesis

H1: Children who have had a previous concussion, a diagnosis of ADHD, LD, or a psychiatric condition (anxiety/depression) will be more likely to perform statistically low at baseline on neurocognitive tests and will report more symptoms at baseline. Research questions that were investigated include, 1) What are the risk factors associated with a low baseline score in children? 2) "Were the children with pre-existing conditions more likely to report more symptoms at baseline?" The independent variables were the pre-existing conditions previous concussion, learning disability (LD), attention/hyperactivity disorder (ADHD), and psychiatric condition or psychological distress (anxiety/depression). The dependent variables were neurocognitive scores of the ImPACT and the Total Symptom Score derived from the self-report of the Symptom Checklist (included on ImPACT).

Chapter Two: Review of the Literature

Understanding Concussion

Concussion in Sport Group

The concussion in Sport Group (CISG) is a panel of international experts that share an interest in concussion understanding and research; they meet internationally approximately every four years to discuss the current state of knowledge in the field of SRC. In 2001, The 1st International Symposium on Concussion in Sport took place in Vienna to discuss the status of concussion diagnosis and management (Aubry et al., 2002). The panel reiterated the endorsement that neuropsychological testing should serve as the foundation of concussion management. In 2004, the 2nd International Symposium took place in Prague (McCrory et al., 2004), and the pediatric population was briefly acknowledged. At the 3rd International Conference on Concussion in 2008 (McCrory et al., 2009, the panel first recognized a plethora of modifying factors which exist in concussion management; these may include gender, experiencing symptoms for more than 10 days, losing consciousness for more than 1 minute at the time of injury or experiencing amnesia directly before or after the injury, previous concussion, age, pre-existing conditions such as migraine, depression, psychiatric disorder, ADHD, LD, sleep disorder, medication, behavior style, and type of sport/activity (McCrory et al., 2009). Importantly, this was the first panel that included youth in the Statement. The previously established research regarding modifiers was reaffirmed at the 4th International Symposium on Concussion in Sport in Zurich (McCrory et al., 2012). Moreover, the Zurich Panel further expanded the consensus statement regarding children and adolescents, and also addressed school accommodations and specific considerations for confounding variables such as ADHD and LD (McCrory et al, 2012).

At the most recent 5th International Conference on Concussion in Sport in Berlin in October 2016 (McCrory et al., 2017), the panel of experts screened approximately 60,000 peer reviewed articles on SRC to summarize each topic and provide updated recommendations. The statement is divided into sections pertaining to the newly established "11 R's of SRC", thereby providing a framework of concussion management which includes Recognize; Remove; Re-evaluate; Rest; Rehabilitation; Refer; Recover; Return to sport; Reconsider; Residual effects and sequelae; Risk reduction. The authors recognized that more consistent paradigms need to be established for youth to continue to strengthen research with the pediatric population. They suggest ages 18 and younger include children and adolescents, which can be separated into a younger pediatric group (ages 5-12) and adolescents (ages 13-18). The CISG further acknowledged that there is very little research to date on children younger than age 13, and indicated that this should be considered a "priority" in the future in order to establish if children with SRC need to be managed differently from adults (McCrory et al., 2017)

Definitions

Various entities have offered multiple conflicting definitions of concussion. The 5th International Conference on Concussion in Sport in Berlin, 2016 defined concussion as a "traumatic brain injury (TBI) induced by biomechanical forces" that may be caused "either by a direct blow to the head, face, neck or elsewhere on the body with an impulsive force transmitted to the head" (McCrory et al., 2017). Likewise, the American Medical Society for Sports Medicine (AMSSM) describes concussion as a "traumatically induced transient disturbance of brain function involving a complex pathophysiologic process" (Harmon et al., 2013). The Centers for Disease Control and Prevention (CDC) currently define concussion as a type of traumatic brain injury (TBI) caused by a bump, blow, or jolt to the head or by a hit to the body that causes the head and brain to move rapidly back and forth (CDC, 2017). The CDC no longer specifies loss of consciousness in the definition of concussion; this was previously included. The formal medical definition of concussion as developed by the American Academy of Neurology (AAN, 2017) is a clinical syndrome characterized by immediate and transient alteration in brain function, including alteration of mental status and level of consciousness, resulting from mechanical force or trauma. Despite the lack of precision in the definition of concussion, it is generally agreed upon by concussion experts that concussion is a form of TBI that usually occurs from some mechanism of injury, is followed by a distinct set of signs and symptoms, results in acute disruption of neurologic function, and resolves spontaneously (McCrea et al., 2017). Generally, a concussion describes a functional disturbance rather than a structural injury to the brain, even though neuropathological changes are also present. Therefore, standard structural imaging such as an MRI does not detect brain impairment in concussion. However, brain scanning or imaging may be employed to rule out other serious conditions such as a cerebral bleed (McCrea et al., 2017; Harmon et al., 2013).

Incidence and prevalence

The American Medical Society for Sports Medicine indicated that the recent estimated rate of sports related and recreational concussions annually in the USA is 3.8 million (Harmon et al., 2013). However, that is likely a very conservative estimate because it is generally understood that as many as 50% of concussion cases go unreported for various reasons. Sports that have been recognized as having the highest rates of concussion are in football, hockey, rugby, soccer, and basketball (Harmon et al., 2013). On a global level, incidence rates of hospital-related mild traumatic brain injuries are estimated to be 100 to 300 per 100,000 according to the World Health Organization Collaborating Task Force on Mild Traumatic Brain

Injury (Cassidy et al., 2004). These are minimal estimates because many, if not most people who sustain a head injury do not obtain hospital treatment, and some do not ever present to a physician (McCrea; 2017). Furthermore, there is a lack of consensus on the identification and diagnosis of concussion and mild TBI in Emergency Departments (EDs) and other trauma settings, as well as variability among responders assessing for head injury. Furthermore, the effects of a concussion may not be known until after other more severe injuries have been addressed (Bakhos, 2010; McCrea et al., 2017).

Epidemiology and risk factors

Female sex, the sport being played, and the position are identifiable risk factors in sports-related concussion (Laker, 2011). Males are more likely to sustain a concussion and exhibit higher incidence rates overall (Borich et al., 2013). Reasons for this may be a greater likelihood of playing an impact sport such as football or hockey. However, recent research has indicated that females may experience worse outcomes or longer recovery than males (Borich et al., 2013; Ellemberg et al., 2009). Females may report a greater number of symptoms, more severe symptoms, and experience more cognitive deficits (Covassin et al., 2013). In addition, a medical history that includes a previous concussion, history of headaches, or history of migraines has been documented to be associated with a greater risk of concussion (Meehan et al., 2013).

Finnoff, Jeising, and Smith (2011) discussed the current research on serum biomarkers for concussion. In addition to biomarker serums, they summarized several risk factors associated with concussion. Female gender, fatigue, and previous concussion were variables related to sustaining a concussion, and female gender, prior concussion, preexisting anxiety or depression, preexisting learning disorder, pre-injury migraine headaches, post-concussion amnesia, high school age (compared with college or professional athlete age), and excessive post injury exercise were risk factors associated with poor recovery. Being younger than age 18, recent history of concussion, and persistent symptoms of concussion was correlated with a higher risk of catastrophic injury.

Physiology

Research from experimental work with animals and post-injury imaging of humans has documented a metabolic cascade that results from the biomechanical insult to the head after a concussion, wherein the homeostasis of the brain of the injured person is disrupted (Signoretti et al., 2011; McCrory et al., 2012; Giza and Hovda, 2001). Following injury, stretching and shearing occurs in neuronal cell membranes and axons in the brain, which contributes to a temporary ionic disruption and an energy crisis in the brain (Shrey et al., 2011. This neurotoxicity and metabolic disturbance is the root of post-concussion symptoms. This also makes the injured cells more vulnerable to a second concussion which could cause further and sometimes irreversible damage (Signoretti et al., 2011). These physiological changes leave the brain vulnerable for subsequent trauma. In extreme and rare situations, a phenomenon called second-impact syndrome can occur when a second injury occurs soon after the first with catastrophic consequences, and sometimes death (Shrey et al., 2011).

A review by Shrey et al. (2011) highlighted the necessity of considering the nuances of the developing or immature brain during pediatric mTBI. There is growing evidence to suggest that the young brain may be more vulnerable to repeat concussions due to the impairments in neural activation and plasticity, as well as increased sensitivity. Cerebral blood flow may increase within one day of injury in pediatric cases and then decrease for a period of days (Giza & Hovda, 2001; Bakhos, 2010). Furthermore, children may be more at risk simply due to the fact of exposure to contact sports and duration of this exposure throughout childhood, adolescence, and into adulthood (Sahrey, Griesbach, and Giza, 2011).

Identification

Signs and Symptoms

Concussion is associated with a constellation of symptoms that may or may not include loss of consciousness. Four broad domains can be used to describe the symptoms and signs that typically present with acute concussion: physical, cognitive, emotional, and sleep-related. Physical or somatic complaints include headache, nausea, vomiting, dizziness, fatigue, vision problems, sensitivity to light and/or sound, and numbness or tingling. Cognitive symptoms include mental fogginess, feeling slowed down, difficulty concentrating, trouble remembering, and forgetfulness of recent events/information, confusion, answering questions slowly, repeating questions, and reduced reaction time. Emotional symptoms include crying, irritability, sadness, or anxiety. Sleep disturbances include sleeping either more or less than usual, difficulty falling asleep, and drowsiness. (Harmon et al., 2013; McCrory et al., 2009, 2012). Importantly, symptoms are believed to be nonspecific because they occur across many medical conditions, so it can be difficult to assert whether or not they are due to a head injury. For this reason, the identifying forceful event is important to identify as the precursor to the presentation of symptoms (McCrory et al., 2017).

Overview of sideline protocol

The protocol for a sports concussion sustained during play involves immediate removal from play and sideline evaluation (CDC, 2015; McCrory et al., 2012, 2017). After first aid and emergency management concerns are properly addressed, the player's concussion should be assessed, and if diagnosed with a concussion or one is suspected, should not return to play the same day following the injury. The next step in a multimodal approach to concussion management is a symptom check and screening of cognitive functioning. Over the past 10 years or so, many standardized checklists have been developed to document the patients' experiences as well as to monitor changes in symptom levels during the recovery period. These are typically self-report rating scales (McCrea et al., 2017). Brief, standardized neuropsychological assessments are typically employed as part of a sideline evaluation (McCrory et al., 2012, 2017; Harmon, 2013).

Management Approach

Multidimensional Evaluation

The diagnosis, assessment, and management of concussion often incorporates and necessitates a multidisciplinary approach which may include emergency responders, sports team coaches, athletic trainers, school personnel, primary care physicians, neurologists, neuropsychologists, psychologists or other mental health providers, and physical therapists (McCrea et al., 2017; Harmon et al., 2013). The National Academy of Neuropsychology recommends neuropsychological evaluation for the diagnosis, treatment, and management of concussion in terms of return to learn, return to play, and return to work decisions. The results can provide useful data that can be interpreted for identification and management of such impairments (Coppel, 2011). One of the most widely used assessments for concussion testing is the ImPACT (Lovell, 2006), which is the only test cleared for use in concussion management by the Food and Drug Administration (FDA).

In contrast, the AMSSM indicated in their 2013 position statement (Harmon et al.) that most concussions can be "managed appropriately" without necessitating neuropsychological testing. However, the authors acknowledge that in certain circumstances neuropsychological tests (NPs) add value to assessing cognitive function and recovery in sports concussion. When computerized NP is used for management, the authors underscore the importance of testing done by trained professionals who are familiar with the psychometrics of specific tests and note that paper and pencil NP tests may be more comprehensive or useful for testing other domains. Biomarkers are currently being explored by various researchers to assist in concussion diagnosis, but the current body of evidence is scant (Finnoff, Jeising, and Smith, 2011; McCrory et al., 2012).

In conjunction with assessing cognitive functioning, a graded symptom checklist is typically utilized that allows the patient to rate the type and severity of symptoms, allowing progress monitoring throughout recovery. Many of the neuropsychological assessment tools for concussion have an embedded symptom checklist that allows the clinician and patient to readily track many aspects of functioning (McCrory et al, 2012; McCrea et al, 2017; Lovell, 2006).

Treatment

The hallmark of concussion management is marked by physical and cognitive rest in the acute phase until symptoms resolve, followed by gradual physical exertion before medical clearance and return to play (RTP), and if applicable, return to school (McCrory et al., 2009, 2012, 2017; Moser, Glatts, and Schatz, 2012). Graded physical exertion consists of engaging in activity such as light exercise until the patient begins to feel symptoms returning, thus determining a threshold for activity. More recently, Moser and colleagues (Moser, Schatz, Glenn, Kollias, and Iverson, 2015) examined prescribed rest as a treatment for adolescents who had prolonged post-concussion symptoms, and the results suggested improvement with both neurocognitive scores and symptom reduction. Notably, 77% of the 13 participants in this sample endorsed a premorbid or comorbid condition of ADHD, LD, or two previous concussions. Therefore, it is recognized that recovery can be complicated by various factors, and thus, guidelines need to be flexible and concussion management must be individualized (McCrory et al., 2012). In contrast, more recent data compiled from the Consensus (McCrory et al., 2017) contend that not enough strong evidence exists to prescribe complete rest as treatment for concussion, instead favoring a gradual and progressive increase in activity after an initial brief period of rest following the acute phase of the injury (24-48 hours). Psychological factors must be appropriately addressed as well, and pharmacological intervention may be applied in certain situations (sleep, headache, anxiety). Individual symptoms are also treated with the established protocol for that symptom.

Time course of recovery

Recent findings from a study by McCrea, Broschek, & Barth (2015) suggest that a window of cerebral vulnerability (WoCV) exists following concussion; this is a critical period that goes beyond the clinical recovery of a concussion when the brain remains compromised physiologically and is at risk for a second injury. First, there is an acute period of clinical characteristics such as symptoms and functional deficits, combined with physiologic disruption. During the post-acute phase, the clinical signs resolve, and physiological dysfunction persists. It is during this time when many athletes return to play and thus are at-risk for repeat concussions. Last, there is complete clinical and physiological recovery. Ideally, a prevention-based return to play and return to learn model is indicated when full clinical and physiological recovery is reached (McCrea, Broschek, & Barth, 2015). However, the CISG does not define a specific amount of time for SRC recovery (McCrory et al., 2017).

There is a typically predictable and sequential course of recovery; however, in a small percentage of cases, prolonged recovery occurs, and post-concussive symptoms may linger. Although it was previously estimated that the majority of concussions (80-90%) resolve within

7-10 days (McCrory et al., 2012), the most recent data has extended the general recovery time for adults to up to two weeks (McCrory et al., 2017). However, the recovery time may be longer in the pediatric population, and data from the 2016 Conference held in Berlin indicate that the pediatric population may require up to four weeks for recovery; this has also been extended from earlier concussion guidelines which indicated about two weeks for children (McCrory et al., 2012, 2017). Symptoms that continue beyond the expected recovery period may warrant a further diagnosis of Post-Concussion Syndrome (Broshek et al., 2015).

Post-concussion syndrome

Post-concussion syndrome is diagnosed when a set of symptoms persist beyond the expected recovery period of a concussion. The symptoms associated with post-concussion syndrome include impaired attention, concentration and memory, headache, dizziness, mental fogginess, photosensitivity, noise sensitivity, and emotional liability which persist beyond the usual recovery period of about two weeks for adults and up to four weeks for children (McCrory et al., 2017). Importantly, the exact period of the time when the subacute phase of a concussion ends and when post-concussive symptoms persist has not been established. Thus, diagnosis varies among clinicians. A study by Alves, Macciocchi, and Barth (1993) investigated the type, frequency, and duration of post-concussive symptoms in adults and found that headache was the most frequently reported symptom both upon discharge from acute hospitalization and at three months post-injury, followed by headache in combination with dizziness. In this sample, most patients reported no symptoms one year later, but some small percentage experienced persistent post-concussive symptoms. Similarly, Yeates et al. (2009) found that children who suffered a mTBI were more likely to present with classic acute and persistent post-concussive symptoms, especially headache (76%), in comparison with children who had sustained an orthopedic injury.

Ellis, Leddy, and Willer (2015) recently proposed a new pathophysiological approach to classifying concussion and PCS. In this extensive literature review, the authors present an evidenced-based approach that further breaks down acute concussions or PCS into specific disorders, called PCD (post-concussion disorders) based on certain characteristics. They classify PCD into three different subtypes based on a set of persistent concussion symptoms and impairments. Physiologic PCD is marked by continued alterations in global cerebral metabolism. These patients tend to report mild symptoms or no symptoms at rest, but continue to experience exacerbation during mental or physical stimulation. The second type of PCD the authors identified is vestibulo-ocular PCD, which is characterized by disruption of the vestibular and oculomotor systems. Patients with vestibulo-ocular PCD may complain of dizziness, light-headedness, vertigo, various vision problems, gait problems and impaired convergence. The third subtype of concussions are cervicogenic, which is characterized by muscle trauma and inflammation and cervical spine dysfunction. Complaints may include neck pain, stiffness, soreness, and decreased range of motion as well as occipital headaches which worsen with head movement.

McCrea, Broshek, and Barth (2015) discussed the importance of addressing who is most at risk of prolonged recovery or poor outcome in a sports related concussion as well as the importance of modifiers in future research concerning concussion management. The authors suggest that it will be important to study the influence of individual factors and vulnerabilities on recovery and outcomes (McCrea, Broschek, and Barth, 2015). Research has suggested that concussion is usually followed by a "gradual, uncomplicated course" of recovery, which typically lasts about 1-2 weeks (McCrory et al., 2017). However, recent studies indicate that more severe concussions or the presence of a modifying condition such as history of mental illness, may prolong both the symptoms and cognitive deficits beyond this period. Furthermore, the likelihood of sustaining another head injury is particularly high during this time. Although the previous Consensus Statement on Concussion (McCrory et al., 2012) indicated that the expected recovery window is about 7-10 days after first concussion, new data indicate a slightly longer window, about two weeks for adults and four weeks for children (McCrory et al., 2017).

Pre-existing Conditions as Modifiers in Concussion

LD/ADHD

There is a growing body of research that supports ADHD as a modifying factor in concussion with respect both to occurrence and to recovery. It is estimated that as many as 16 to 20% of children in the United States, ages 3-17 are diagnosed with ADHD or with a learning disability (Zuckerman et al., 2013; American Psychological Association, 2013). In a study by Zuckerman et al. (2013), children who were administered the ImPACT, having had a prior diagnosis of ADHD, had significantly lower verbal memory, visual memory, and visual motor processing, but reaction time, impulse control, and symptom scores were observed to be higher. Similarly, children in the study with a learning disorder had lower neurocognitive scores but did not exhibit differences from the control group with reaction time and impulse control. More recently, Nelson et al. (2016) investigated the relationship between ADHD and LD diagnosis and concussion history in high school and collegiate athletes and performance on baseline neurocognitive concussion assessment measures. They found that athletes with a pre-existing diagnosis were more than twice as likely to report a history of more than 3 concussions. Athletes who endorsed having both ADHD and LD were more than three times as likely to report a history of more than three concussions. Furthermore, athletes with no prior history of concussion endorsed more baseline symptoms and had lower assessment scores (Nelson et al., 2016).

Bonfield et al. (2013) investigated the impact of ADHD diagnosis on the recovery from closed mild traumatic brain injury in youths ranging from ages 6-17 years using retrospective data analysis; they found that patients with ADHD were significantly more disabled after the injury than were children with no previous diagnosis of ADHD when other factors such as age, sex, length of hospital stay, injury type, and other variables were controlled. The authors suggest the possibility that these children may be more disabled than their nondisabled peers at baseline, which would make them appear more disabled during recovery as well. They also acknowledge the issue of a possible third confounding variable of SES because low SES is associated with higher rates of ADHD (Bonfield et al., 2013). This acknowledgement is in line with the emerging data from the most recent Consensus on Concussion in Berlin (McCrory et al., 2017), which indicates that ADHD appears to be predictive of lower baseline scores in children, but not of recovery timelines.

Depression/Anxiety

There is a bidirectional relationship between emotional functioning and cognitive functioning (because emotions are in fact a neurocognitive process). That is, brain-based impairments can cause emotional disruption, and emotional functioning can affect cognitive processing (Coppel, 2011; Levin, 2007). Both cognitive and emotional symptoms may persist beyond physical symptoms in a concussion or PCS or be the hallmark of symptoms of the head injury. Physical symptoms may include headache, dizziness, or vision problems. Cognitive symptoms may include reduced focusing ability and difficulty concentrating, planning problems, difficulty switching tasks, and memory complaints. Emotional symptoms often consist of irritability, lability, anxiety, and depression. Particularly in the context of sports concussion, the reporting of cognitive and emotional symptoms may be minimized when a symptom check is performed

(Coppel, 2011). Thus, it is important to have sensitive and specific instruments to identify these symptoms.

Major depressive disorder occurs in approximately 7% of the U.S. population (American Psychological Association, 2013). Cognitive symptoms associated with depression include impairments in memory, information processing speed, attention, and executive functions (Levin et al., 2007; Austin et al., 2001). Additionally, brain imaging of depressed people has shown frontal and temporal lobe changes, such as a smaller hippocampus and slower cell communication (Levin et al., 2007; Videbach & Ravnkilde, 2004). Retrospective investigations of the brains of depressed individuals have even demonstrated a negative correlation between hippocampal volume and number of episodes of depression. Although there is limited data thus far examining the effect of psychological distress on baseline functioning, Bailey et al. (2010) found significant interactions between numerous psychiatric conditions and baseline concussion neurocognitive performance, such as anxiety, depression, substance abuse, and suicidal ideation, thus demonstrating that emotional distress has a moderate to large effect negative effect on baseline scores. (Bailey et al., 2010). In contrast, a study by Cicerone and Kalmar examined the interaction of pre-existing depression at baseline, and the results were not significant, but the study was very small (20 individuals with a history of depression).

Although research has documented that pre-existing conditions seem to increase the likelihood of sustaining a concussion, less is known about the recovery of individuals who meet this criterion (Nelson et al, 2016). Moreover, even less is known about the recovery trajectory from post-concussive syndrome of children and adolescents with preexisting disorders (Preece & Geffen, 2007; McCrory et al., 2009). A study by Preece and Geffen (2007) examined the effect of pre-existing depression on the acute cognitive sequelae of mTBI and found an interaction between depression and head injury, particularly with word recognition when assessed 24 hours after a head injury. This study had a small sample size and the age of participants ranged from 16-60. Other research involving a pediatric sample with prolonged concussion recovery (Corwin et al., 2014) found that patients with premorbid anxiety took more than twice as long to recover completely, compared with patients without anxiety, and that patients with preexisting depression took 2.2 times longer to recover. Furthermore, within the pediatric range of 5-18, children who were ages 13-14 experienced the longest recovery period of about 40 days (Corwin et al., 2014).

A study by Corwin et al. (2014) examined characteristics of prolonged concussion recovery among children ages 5-18 who were referred to a specialty sports clinic. The results of this study identified numerous traits that were consistent with longer recovery including a history of anxiety or depression; reporting dizziness as a primary symptom, convergence problems, and history of previous concussion. The median time the children took to return to school with a modified program (half day schedule) or accommodations was 12 days, returning to school on a full-time basis with no accommodation was 35 days; reporting no further symptoms was 64 days, and returning to play sports was 75 days. Moreover, nearly three-quarters of the pediatrics experienced symptoms for more than 4 weeks (Corwin et al, 2014). This study demonstrated that pediatric populations may require longer time to recover from concussions, especially if one of these pre-existing criteria is present. However, these studies did not have a baseline of comparison for this population.

In an extensive literature review by Broschnek, Marco, and Freeman (2015), the authors acknowledged the importance of understanding the role that pre-existing psychological attributes have on the role of concussion assessment and recovery. Pre-morbid and comorbid anxiety in individuals increases the likelihood of post-concussion syndrome. Therefore, the use of cognitive behavioral strategies that serve to shift cognitive biases and misattribution of symptoms in addition to psychoeducation, reassurance, and relaxation techniques play a key role in the treatment and recovery of concussion with this population (Broschnek, Marco, and Freeman, 2015).

Sleep

Sleep has also been found to play have an impact on neurocognitive functioning and symptoms. A study by Sufrinko, Johnson, and Henry (2016) examined the influence of sleep duration and sleep-related symptoms at baseline in adolescents and found that reduced sleep negatively impacted neurocognitive scores on the ImPACT and was associated with a higher number of reported sleep-related symptoms. Similar observations were observed by Mihalik et al. (2013), wherein reduced sleep the night before baseline testing was correlated with a greater number of symptoms and higher total symptom severity.

Assessment

Baseline Testing

Barth et al. at the University of Virginia (1989) developed the model for baseline and post-concussion assessment which has since become the standard for the neuropsychological assessment of athletes across professional, collegiate, and high school sports teams (Coppel, 2011). This model is distinct from traditional neuropsychological assessments which are both comprehensive and time-consuming. Instead, baseline testing employs a relatively brief battery of assessment tools that targets cognitive domains most often impacted by concussion. These domains usually include memory, attention, speed of mental processing, and reaction time. By capturing a snapshot of these specific areas, it is feasible to screen many athletes in a short amount of time, yielding an individual standard for each athlete. Therefore, baseline assessments are typically performed prior to a sports season and can then serve as a basis for comparison should an athlete sustain a concussion. After sustaining a concussion, an athlete is given a series of post-injury assessments to determine the moment at which deficits and symptoms cease. The standard practice for return to play decisions involve the athlete returning to baseline or better both neurocognitively and symptomatically (Coppel, 2011).

Baseline testing serves as a comparison guideline for measuring cognitive skills and symptoms pre-and post-injury in athletes. Supporters of baseline testing believe that obtaining a baseline measure of functioning is a useful tool in recovery, especially with individuals who fall below or above the mean at baseline or have a pre-existing condition such as ADHD (Iverson & Schatz, 2015). The utility of pre-injury testing has been acknowledged across disciplines involved in concussion management. For example, Guskiewicz et al. (2004) pointed out in the National Athletic Trainers' Association Position Statement on sports concussion management that baseline testing demonstrates the athlete's personal starting point while controlling for extraneous factors that may be present such as attention or learning problems, as well as effects from previous concussions. By obtaining a snapshot of both neurocognitive performance and symptoms at baseline, professionals can better identify deficits that are due to any new injury that occurs after baseline.

However, the role of baseline testing for concussion management remains in question, as does the value of neuropsychological assessment. The American Medical Society for Sports Medicine (AMSSM) indicated in their position statement (Harmon et al., 2013), that most concussions can be "managed appropriately" without necessitating neuropsychological testing. Meanwhile, they acknowledge that in certain circumstances neuropsychological assessments add value to assessing cognitive function and recovery in sports concussion. When computerized assessments are used for management, the authors underscore the importance of testing done by trained professionals who are familiar with the psychometrics of specific tests, and note that paper and pencil cognitive tests may be more comprehensive or useful for testing other domains.

There is currently little evidence to support the necessity of baseline testing compared with not having baseline data, with respect to the time and cost associated with it. In addition, there are many administration variables and test taking conditions which may render the baseline data invalid. What is not yet known is the magnitude with which these embedded validity measures can detect sandbagging (deliberate poor performance), confusion about the test, external environmental distractions, or a combination of variables (Iverson & Schatz, 2015). However, researchers also recognize that many athletes who produce statistically invalid scores have identified conditions such as ADHD or LD, which can lend to variable scores (Iverson & Schatz, 2015). In these cases, the test maker may deem a test as "invalid" when in fact it is a rather accurate picture of baseline functioning (Schatz, Moser, Solomon, Ott, and Karpf, 2012). Moser, Schatz, and Lichenstein (2014) underscored the importance of proper standardized administration and interpretation of computerized neuropsychological baseline and post-concussion testing to increase quality control and decrease the prevalence of invalid scores.

One cross-sectional study (Schatz et al., 2012) examined the baseline ImPACT scores of adolescent and young adult athletes and found that the online version yielded considerably fewer invalid results (6.3%), compared with the desktop (11.9%) version. The reason for this is that the online version automatically corrects for left-right confusion but the desktop does not, and these errors account for as many as 50% of the invalid tests. Thus, it is important that computerized testing is administered by trained professionals who are knowledgeable about the specific tests they are using (Schatz et al, 2012). In a similar cross-sectional study that examined the prevalence of invalid baseline scores on neurocognitive tests utilizing the ImPACT test in a pediatric population ages 10-18 (Lichtenstein, Moser, & Schatz, 2013), the results revealed that both age and test setting were modifiers. Younger children, ages 10-12, were more likely to have invalid test results, as well as children who took their baseline testing in a large group of about 10 athletes in a non-standardized setting, compared with a small group of about 1-3 athletes at a formal testing site (Lichtenstein, Moser, & Schatz, 2013). Vaughan, Gerst, Sady, Newman, and Goia (2014) found that children ages 5-18 performed similarly on the ImPACT at baseline when given either in a group setting of two participants or individually when administration was properly standardized by trained test administrator, suggesting that difference across settings may be attributable to variances among test administration and supervision, not the testing environment.

ImPACT

The ImPACT is a nationally normed, internet-based assessment tool designed to manage and monitor athletes who are at risk for or who have experienced a concussion; it has been demonstrated to have high reliability and validity (Iverson et al., 2003). Administration of the test takes approximately 25 minutes and consists of six neuropsychological subtests, which measure attention span, working memory, sustained and selective attention time, non-verbal problem solving, and reaction time. The ImPACT yields five composites: verbal memory, visual memory, visual motor speed, reaction time, and impulse control, as well as a cognitive efficiency index. There are equivalent alternate forms available for each test taker to decrease the likelihood of practice effects if he or she will need to take multiple tests if a concussion occurs. The demographic section of the ImPACT asks a standard set of questions pertaining to health history and comorbid conditions which include the current variables of interest. The ImPACT also includes the Post-Concussion Symptom Scale (Lovell & Collins, 1998), which is a checklist that consists of 22 items and utilizes a 6-point scale, yielding a Total Symptom Score (Lovell, 1999). Results are provided via a comprehensive report.

The clinical usefulness of the ImPACT test was demonstrated in a study by Schatz, Pardini, Lovell, Collings, and Podell (2006), which highlighted the fact that this battery is both a sensitive and specific tool regarding cognitive performance and symptom checking in reflecting concussion. To this end, the ImPACT test has been demonstrated to be a very useful instrument in identifying and managing concussions for several reasons. First, the test is relatively brief, so it can be used as a baseline measure, a screening tool post injury, and in progress monitoring. Second, the ImPACT test examines specific neurocognitive domains that are often compromised during the concussion, such as reaction time, processing speed, visual memory, and impulse control. Third, the ImPACT test includes a symptom check, and offers an additional symptom check after taking the test. Last, because it is computerized, it can be given multiple times with different versions, thus reducing the likelihood of practice effects (Schatz et al., 2006).

Concussion in Youth: An Emerging Frontier

Summary of Child Research on Concussion

Recently, concussion research has focused much more attention on the pediatric population. The 1st Consensus Statement on Concussion in Sport held in Vienna in 2001 (Aubry, 2002) offered no child specific recommendations. The 2nd Consensus Statement in 2004 briefly acknowledged children and adolescents (McCrory et al., 2004). The 3rd Consensus in 2008 in Zurich included the pediatric population in their Statement (McCrory et al., 2008), and the 2012 Consensus Statement in Zurich (McCrory et al., 2012) expanded on concussion in youth and addressed school considerations and specific considerations for confounding variables such as ADHD and LD. In examining current trends in research on children, it is necessary to emphasize the fact that new data continue to emerge in this area of concussion. A recent systematic review by Davis et al.,(2017), evaluated the existing published evidence regarding sports concussion management in children and adolescents in preparation of the 5th International Consensus Conference on Concussion in Sport in Berlin 2016 (McCrory et al., 2017). When age was used involving children in concussion, specifically, the ages 5, 8, 10, 12, 13, 15, and 18 were most often used and 12 was the mid -point categorically (Davis et al., 2017). The most recent literature suggests that the pediatric population may take considerably longer, up to four weeks, to recover from a sports-related concussion. The research studying children under age 12 was scarce. At this point, the existing literature does not "adequately address the question of age groups in which children with SRC should be managed differently from adults" (Davis et al., 2017, McCrory et al., 2017). Similarly, there are limited data that expressly differentiate the typical symptoms and signs associated with concussion in youth with sports related concussions from those types of concussions in adults, and also differentiating those in younger children from those in adults (Davis et al., 2017). Also, it is important to recognize that considerations for academics need to be addressed when discussing this population. Dessy et al. (2014) described important considerations in test evaluation of concussion management practice. The same modifying factors that affect concussion prevalence and recovery need to be considered when interpreting concussion test data.

Differences in acute concussion. A review by Sahrey, Griesbach, and Giza (2011) highlighted the necessity of considering the nuances of the developing or immature brain during pediatric mTBI. The metabolic cascade that follows a concussion has been well documented.

Following a biomechanic injury, stretching occurs in neuronal cell membranes and axons, which contributes to a temporary ionic disruption and energy crisis in the brain. Cerebral blood flow may increase within one day of injury in pediatric cases and then decrease for a period of days (Sahrey, Griesbach, and Giza, 2011). These physiologic changes leave the brain vulnerable for subsequent trauma. In extreme and rare situations, a phenomenon called second-impact syndrome has been documented; this occurs when an individual sustains a second concussion shortly after the first with catastrophic consequences. Regarding the pediatric population, there is growing evidence to suggest that the young brain may be more vulnerable to repeat concussions due to impairments in neural activation and plasticity as well as increased sensitivity. Furthermore, children may be more at risk simply due to the fact of exposure of contact sports and duration of this exposure throughout childhood, adolescence, and into adulthood (Sahrey, Griesbach, and Giza, 2011).

Assessment in children. Recent data indicate that "the widespread routine use of baseline computerized neuropsychological testing is not recommended in children and adolescents (Davis et al., 2017). One of the reasons cited for this includes the fact that the brains of young children, particularly ages 5-11, change so rapidly that a baseline assessment would need to be performed about every 6 months to be considered valid. Most of the literature thus far on the utility of computerized neuropsychological testing for diagnostic and assessment purposes in youth sports concussion has involved adolescents. Computer and paper-and-pencil neuropsychological tests were sensitive to cognitive impairments in the areas of processing speed, verbal and visual memory, and reaction time, within the first 48 hours of a concussion and about 10-14 days post-injury (Davis et al., 2017).

Special Considerations for Recovery in Youth. The recent research on children's recovery suggests that most children recover from concussion and return to play within four weeks. Limited data indicate that teenagers may take longer to recover compared with younger children and college age adolescents (Davis et al., 2017), such as the Zemek et al. study (2016), which indicated that being age 13 or older was one of the nine variables associated with an increased risk of developing Persistent Post Concussion Symptoms (PPCS). Another study suggested that 13-14-year-olds may take longer to recover than other age groups (Corwin et al., 2014). To date, there are eighteen studies that address prolonged recovery in children (Davis et al., 2017). Acute headache, migraine and dizziness were consistently identified in these studies as risk factors, along with female sex and prior concussions. In one retrospective study of the pediatric population ages 5-18 years who demonstrated prolonged concussion recovery at a specialty clinic (Corwin et al, 2014), the results revealed that the median number of days before returning to school on a modified schedule or participating in homebound instruction was 12 days and the median number of days to returning to school full time without accommodations was 35 days. The median time for reporting a symptom free state was 64 days, and the median time until students were cleared to participate fully in all activities was 76 days. Furthermore, the Corwin et al. (2014) study revealed that patients with pre-existing anxiety took more than twice as long to reach full clearance, and that patients with pre-existing depression took more than twice as long to become symptom free. Patients with depression required an increased number of academic accommodations. Anxiety was associated with a recovery of more than four weeks in 100% of the patients that had anxiety prior to the concussion. Children ages 13-14 took 1.8 times longer to recover than children under age 12 (Corwin et al., 2014), and adolescents ages 15-16 took the longest to return to school. The youngest children under age 12 took the longest to have resolved symptoms but were prescribed school accommodations less often than other children.

Rest and activity. Followed by a brief period of cognitive and physical rest after head injury, it is recommended that children and adolescents be monitored with gradual "symptom limited" physical and cognitive activity (Davis et al., 2017; McCrory et al., 2017). Groom et al. (2016) investigated the relationship between participation in physical activity within 7 days of a concussion and the occurrence of persistent post-concussion symptoms (PPCS) in children and adolescents ages 5-18. They broadly categorized any form of exercise spanning from light aerobic activity, moderate, and full exercise (contact sport), compared with no activity (rest). They considered PPCS to be three or more new or worse symptoms 28 days after injury, compared with their presumed baseline. In this study, early participation in physical activity was associated with a lower risk of PPCS, especially light physical activity. In a recent systematic review, (Davis et al., 2017), there was no validated data supporting a prescribed amount of time for cognitive or physical rest in children. In adolescents, with a mean of 13.7 years, Thomas et al. (2015) found no effect in neurocognitive or balance outcomes between children who were prescribed rest and control groups, and adolescents who were prescribed strict rest reported more symptoms. Thus, strict rest may be aversive to this population. In sum, the new Berlin consensus continues to recommend rest within the first 24-48 hours following a head injury in children, followed by a gradual return to activity (McCrory et al., 2017).

Concussion and academics. A study by Ransom et al. (2015) studied the effects of concussion on academics in children aged 5-18 and their findings revealed that high school students who reported higher levels of symptoms were associated with more adverse academic effects than children in elementary or middle school. In addition, more severe post-concussion symptoms were associated with more adverse scholastic effects. This provides support for the necessity of proper school-based resources to manage the appropriate recommendations and accommodations following a pediatric concussion to reduce the impact on learning and academic performance following a head injury, including a decrease in the risk of prolonged recovery for children.

Five variables were found to be associated with return to learn practices in the management of pediatric concussion (Davis et al., 2017): age, symptom load/severity, school resources, a medical follow-up, and individual subjects. Adolescents have been found to take longer to recover and report more symptoms than younger children and they tend to be concerned about the scholastic effects. Increased symptoms and severity in children are associated with longer return to school and sports and may necessitate more comprehensive academic accommodations. The resources and concussion practices of the school that the child attends must be taken into consideration because schools with specific guidelines may be more supportive or facilitative in recovery. Children who are followed by a medical provider are more likely to seek out and receive accommodations at school. Finally, school subjects such as math are more difficult for students when they return to school after an injury; these are followed by language arts, arts, science, and social studies (Ransom et al, 2015; Davis et al., 2017). Many students require academic accommodations after returning to school or report difficulty with school after a concussion (Davis et al., 2017).

School-based management. Sadie et al. (2011) identified the need for widespread concussion education and management programs in U.S school systems. The authors highlight the fact that the direct symptoms of a concussion often interfere with efficient information processing which can impede scholastic performance and classroom functioning. The emotional symptoms, which can be arguably a direct or indirect manifestation of the injury or both, can further interfere with cognitive functioning. Furthermore, adolescents are more at risk for pushing through their symptoms before a full recovery is made for fear of missing school or falling further behind. Likewise, the experience itself of persisting symptoms can trigger or increase negative emotions which may exacerbate the individual's perception of his or her cognitive functioning. The authors suggest that a comprehensive schoolwide concussion management program should include the establishment of policies and procedures, staff education, a thorough written plan which addresses accommodations and resources, followed by implementation and active management of the actual plan for students who sustain an mTBI. School personnel such as the nurse, psychologist, designated teacher, and athletic trainer should be integral parts of the committee. Together, this team is responsible for the development and execution of the concussion management that serves to educate, monitor, consult, provide support, and together with a licensed healthcare professional, give clearance for full return to academics.

Post-concussion syndrome (PCS) in children. Zemek et al. (2016) found nine predictive variables associated with the risk of developing Persistent Post Concussion Symptoms (PPCS) in a large sample of 3063 ED patients who were recruited within 48 hours of sustaining a head injury in an emergency department not limited to sports related concussion. The factors were female sex, age 13 or older, pre-existing diagnosis of migraine, having already had a concussion with symptoms lasting longer than one week, headache, noise sensitivity, fatigue, slow response time in answering questions, and at least four errors on the Balance Error Scoring System task (Zemek et al., 2016). Moser et al. (2015) examined prescribed rest as a treatment for adolescents who had prolonged post-concussion symptoms; the results suggested improvement with both neurocognitive scores and symptom reduction. Notably 77% of the 13 participants in the sample endorsed a premorbid or comorbid condition of ADHD, LD, or two previous concussions.

In a study by Schatz et al. (2011), high school athletes who had a history of concussion consistently endorsed more symptoms at baseline compared with athletes with no prior history of concussion, which may provide evidence of enduring symptoms and/or increased sensitivity to symptoms. Similarly, a study by Brooks et al. (2013) found that adolescent athletes who had sustained at least 2 previous concussions did not demonstrate any worse performance on the ImPACT neurocognitive battery at baseline, compared with adolescent athletes who did not have any prior concussions; however, they endorsed a higher number of baseline symptoms. The adolescents in this sample had no pre-existing conditions such as LD or ADHD.

Need for Study

Although there is established literature in concussion research that ADHD and LD are risk factors associated with concussion risk and recovery, this study considered other potential modifying factors, namely presence or history of a mood disorder (anxiety and/or depression), and previous concussion, and specifically, examined low performance at baseline in a preteen/ young adolescent age group. This is consistent with the notion that future directions for concussion research regarding the utility of baseline testing should include "programmatic research relating to the strengths and limitations of baseline testing for improving the accuracy of neuropsychological assessment and determining whether or not improved accuracy contributes to improved management of this injury in athletes" (Schatz and Iverson, 2015).

Bailey et al. (2010) examined the effect of psychological distress on baseline neurocognitive performance testing of college-age football players using archival data from the

Concussion Resolution Index (CRI), a computer-based concussion test and the Personality Assessment Inventory (PAI), a self-report rating scale. This study revealed significant correlations between somatic complaints, depression, anxiety, substance abuse, and suicidal ideation and neurocognitive performance on the CIA. Their findings indicated a negative relationship between psychological distress, particularly suicidal ideation, and both reaction time and processing speed, implicating the importance of screening for comorbidities at baseline and post-concussion assessments. There is even less research on concussion in children who are younger than pre-high school age. However, the growing concern of concussion experts about the lack of research in this area has ignited an international consensus conference to call for more research on concussion in children (McCrory, 2012, 2017; Davis, 2017). Furthermore, the conversation surrounding the utility of baseline testing in children continues to fuel more research (Davis et al., 2017), and even as pediatric versions of well-established neuropsychological tools for concussion are becoming more widespread (ImPACT, 2017), the new recommendations from the 2016 Consensus Statement on Concussion (McCrea et al., in press), are cautioning against the routine baseline testing of younger children.

The present study examined a narrow age range of school aged children (aged 10-14) who engaged in various sports and sought baseline testing from a Center specializing in sports concussion assessment, management, and treatment. This study explored the baseline concussion data on youths involved in ImPACT testing and symptom reporting in order to highlight which modifiers contribute to statistically low scores and in which specific cognitive domains. Furthermore, this study sought to provide more information regarding baseline performance of specific populations to determine if treatment plans and recovery expectations need to be shifted for specific populations, in school, at home, and in sports and activities/social situations. Examining factors associated with low baseline scores may further add to the body of existing literature concerning the utility for or against baseline testing in children in the pre-adolescent/young adolescent age group which has been identified as an area where more research is needed (Davis et al., 2017; MrCrory et al, 2012, 2017).

Chapter Three: Methods

Design

The research design was a retrospective, quantitative, between-participants approach utilizing archival data.

Participants

Participants included deidentified archival data of baseline results obtained via the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) website completed at a small private concussion center located in suburban central New Jersey between 2006 and 2016. Inclusionary criteria were male and female student athletes, ages 10-14 years old that participated in preseason baseline testing during this period. Exclusionary criterion were 1) children whose native language was not English, 2) children whose native country was outside US, 3) children who reported a history of brain seizures, history of meningitis, or treatment for alcohol/substance abuse, 4) children who reported a history of brain surgery, 5) children diagnosed with autism, 6) children who reported that they strenuously exercised within previous 3 hours of taking the ImPACT, 7) incomplete tests profiles and 8) tests flagged ++ by ImPACT, suggesting an invalid score due to high variability.

Participants were male and female student athletes ages 10-14 years old that participated in preseason baseline testing (mean age = 11.74, range 10-14 years, 607 males, 140 females). Of the seven hundred forty-seven participants, 81.2% were male and 18.7% were female. Fifty-one participants (6.82%) were identified as having a learning disability and 696 (93.17%) had no pre-existing learning disability, indicated by parent or caregiver. Sixty participants (8.03%) were identified as having ADHD and 687 had no previously identified ADHD (91.97%). Twelve participants (1.61%) were identified as having a pre-existing psychiatric condition of anxiety or depression and 721 had no identified pre-existing anxiety or depression diagnosis (14 participant responses were left blank by caregivers in this area). Eighty-five participants (11.38%) had one previous concussion; 15 participants had two previous concussions (2.01%); 6 participants had three previous concussions (0.80%), and 634 (84.87%) had no prior concussions (7 participant responses were left blank in this area). It is important to note that inclusion in the previous concussion, ADHD, LD, or anxiety/depression group was obtained from parent/guardian report on the Demographic section of the ImPACT. All participants whose parents/guardians reported that their child had a history or current diagnosis/problem were included in these groups.

Measures

The ImPACT was utilized as the tool for obtaining neurocognitive baseline data from the participants. The ImPACT is a nationally normed, internet-based assessment tool designed to manage and monitor athletes who are at risk for or who have experienced a concussion (Lovell, 2006). The ImPACT website was used to retrieve the data (ImPACT Applications, 2017). The computer test takes 25 minutes to administer and consists of six neuropsychological subtests, which measure attention span, working memory, sustained and selective attention time, non-verbal problem solving, and reaction time. The ImPACT yields five composites: verbal memory, visual memory, visual motor speed, reaction time, and impulse control, as well as a cognitive efficiency index. There are equivalent alternate forms available for each test taker to decrease the likelihood of practice effects if they may need to take multiple tests if a concussion occurs. The demographic section of the ImPACT asks a standard set of questions pertaining to health history and comorbid conditions, which include the current variables of interest. The ImPACT also includes the Post-Concussion Symptom Scale (Lovell & Collins, 1998), which is a checklist that consists of 22 items and utilizes a 6-point scale, yielding a Total Symptom Score (Lovell, 1999). Results are provided via a comprehensive report.

Normative data of the ImPACT was derived from a sample of 424 high school

between the ages of 13 and 15, 158 boys between the ages of 16 and 18, and 83 girls between the ages of 13 and 18. Normative data was based on the natural distributions of scores within these two samples. The distributions of scores within these groups were examined and exact percentile ranks corresponding to the natural distribution of scores were assigned. The authors considered these to be uniform percentile ranks, did not force-normalized the scores, or convert raw scores to standard scores (Iverson, Collins, and Lovell, 2003).

For more detailed information about the ImPACT and the Symptom Checklist, please refer to the ImPACT website at www.impacttest.com (ImPACT Applications, 2017).

Procedure

The purpose of this project was to evaluate the impact of certain pre-existing conditions on baseline neurocognitive scores and symptoms. Institutional review board approval through Philadelphia College of Osteopathic medicine was obtained for this study. Permission to access deidentified archival data was obtained in writing from the director of the testing center. Data were collected through deidentified archival data retrieved from the ImPACT website for children between the ages of 10-years to 14-years who participated in baseline testing at the center. Data were originally collected for baseline assessment between January 1, 2006 and December 31, 2016. Raw scores from each composite were obtained from every participant.

The independent variables were the pre-existing conditions previous concussion, learning disability (LD), attention problems (ADHD), psychiatric condition or psychological distress (anxiety/depression). The impact of symptom reporting was also examined as a possible modifier. The dependent variables were neurocognitive scores and symptom scores. Although the symptom checklist has 22 items that yield a total score, for the purposes of this study only the Total Symptom score was used.

Chapter Four: Results

The current study was guided by the question of whether or not children who have had a previous concussion, a diagnosis of Attention Deficit-Hyperactivity Disorder (ADHD), learning disability (LD), or a psychiatric condition (anxiety/depression) were more likely to perform statistically lower on neurocognitive tests and would report more symptoms of concussion. All students were assessed to obtain baseline measures should future concussion testing be needed after a head injury.

A between-subjects, univariate analysis (ANOVA) was performed to investigate each independent variable. The independent variables were (1) previous concussion, (2) attention-deficit hyperactivity disorder, (3) learning disability, (4) psychiatric condition (anxiety/depression), and (5) reported number of symptoms of concussion. The dependent variables were neurocognitive scores of the ImPACT (verbal memory, visual memory, visual motor, reaction time, impulse control and cognitive efficiency) and the Total Symptom of Concussion Score, derived from the self-report of the Symptom Checklist (included in the ImPACT). Seven hundred and ninety-eight children (aged 10-14 years) completed testing between 2006 and 2016 to obtain baseline scores should future testing be needed after a head injury. A total of 50 participants were excluded from analysis. Forty-four participants were excluded because they had obtained scores flagged "++" by the ImPACT, which denotes the test as potentially invalid due to a high number of inconsistent responses of the test taker. Three participants were excluded because their country of origin was outside of the United States. Three participants were excluded due to missing demographic data (i.e., failure to answer items necessary to test the hypothesis). This yielded a total sample of 747 children who met the established criteria. Please refer to Table 1 for demographics.

Table 1

Demographics

Participants		Number	Percentage
Gender	Males	607	81.25
	Females	140	18.74
Age (years)	Mean	11.72	
	Range	10-14	
LD	Yes	51	6.83
	No	696	93.17
ADHD	Yes	60	8.03
	No	687	91.97
Psychiatric Condition (Anxiety/Depression)	Yes	12	1.61
	No	721	96.52
	Did not report	14	1.87
Prior Concussion	1 Previous	85	11.39
	2 Previous	15	2.01
	3 Previous	6	0.80
	None	634	84.87
	Did not report	7	0.94

Previous Resolved Concussion

As indicated in Table 2, there were no differences in neurocognitive scores in the areas, verbal memory, visual memory, reaction time, impulse control, and symptom reporting between children who had previously sustained a concussion and children with no history of concussion; between children who have had a concussion and those who have not. However, children with a history of at least one previous concussion performed lower on visual motor tasks compared with children with no history of concussion. See Table 1 for comparison of specific neurocognitive domain scores pertaining to concussions.

Table 2

ANOVA Results for Neurocognitive Scores and Number of Concussion Symptoms for Children With and Without a Previous Concussion

ImPACT Domain	Mean Square	F	Significance*
Verbal Memory	15.45	0.158	0.69
Visual Memory	469.23	2.84	0.09
Visual Motor	128.65	3.99	0.046*
Reaction Time	0.035	2.95	0.09
Impulse Control	99.33	2.26	0.13
Cognitive Efficiency	0.009	0.47	0.49
Total Concussion Symptoms	5.21	0.24	0.62

Note: * denotes significance, $p < .05$

Attention-Deficit Hyperactivity Disorder (ADHD)

As indicated in Table 3, children with a previous diagnosis of Attention Deficit-Hyperactivity Disorder (ADHD) performed significantly lower on neurocognitive measures of verbal memory, visual memory, visual motor, reaction time, and cognitive efficiency, compared with children without a learning disability. In contrast, there was no significant difference on neurocognitive measures of impulse control between children with a previous diagnosis of ADHD and children without pre-existing ADHD. However, children with ADHD reported significantly more nonspecific concussion symptoms (i.e., headaches, dizziness, irritability) compared with children with no history of ADHD. See Table 2 for comparison of specific neurocognitive domain scores pertaining to pre-existing ADHD.

Table 3

ANOVA Results for Neurocognitive Scores and Number of Concussion Symptoms for Children With and Without a Previous Diagnosis of ADHD

ImPACT Domain	Mean Square	F	Significance*
Verbal Memory	663.58	6.85	< 0.01*
Visual Memory	987.77	5.99	< 0.015*
Visual Motor	400.85	12.58	< 0.00*
Reaction Time	0.13	10.90	< 0.001*
Impulse Control	114.52	2.16	0.106
Cognitive Efficiency	0.21	10.68	< 0.001*
Total Concussion Symptoms	448.95	21.71	< 0.00*

Note: * denotes significance, $p < .05$

Learning Disability (LD)

As indicated in Table 4, children with a previously identified learning disability (LD), performed significantly lower on neurocognitive measures of verbal memory, visual memory, visual motor speed, and cognitive efficiency compared with children without a pre-existing learning disability. In contrast, there was no difference in reaction time between children with a previously identified learning disability and children without a pre-existing learning disability. Similarly, there was no difference in impulse control between children with a previously diagnosed learning disability and children without a pre-existing learning disability. Furthermore, children with a previously identified learning disability did not report any more symptoms than children without a pre-existing learning disability. See Table 3 for comparison of specific neurocognitive domain scores pertaining to pre-existing LD.

Table 4

ANOVA Results for Neurocognitive Scores and Number of Concussion Symptoms for Children With and Without a Pre-Existing LD

ImPACT Domain	Mean Square	F	Significance*
Verbal Memory	706.62	7.29	< 0.01*
Visual Memory	831.98	5.05	0.025*
Visual Motor	212.35	6.61	< 0.01*
Reaction Time	0.035	2.98	0.085
Impulse Control	11.82	0.27	0.60
Cognitive Efficiency	0.16	8.105	< 0.01*
Total Concussion Symptoms	46.93	2.22	0.14

Note: * denotes significance, $p < .05$

Psychiatric Condition (depression/anxiety)

As indicated in Table 5, there was no difference in neurocognitive scores on measures of verbal memory, visual memory, visual motor speed, reaction time, impulse control, and cognitive efficiency in children with a pre-existing psychiatric condition (i.e., depression or anxiety) compared with children with no history of depression or anxiety. Children with a history of anxiety or depression reported more symptoms, compared with children with no history of anxiety or depression. Notably, only 12 children in this sample had a reported history of anxiety or depression. See Table 4 for comparison of specific neurocognitive domain scores pertaining to pre-existing anxiety/depression.

Table 5

ANOVA Results for Neurocognitive Scores and Number of Concussion Symptoms for Children With and Without a Pre-Existing Psychiatric Condition

ImPACT Domain	Mean Square	F	Significance*
Verbal Memory	10.60	0.109	0.74
Visual Memory	2.31	0.014	0.91
Visual Motor	3.15	0.097	0.76
Reaction Time	0.005	0.41	0.52
Impulse Control	45.455	1.055	0.31
Cognitive Efficiency	0.015	0.76	0.38
Total Concussion Symptoms	312.06	16.02	<0.000*

Note: * denotes significance, $p < .05$

Number of Concussion Symptoms

The 22 symptoms of concussion signs and symptoms by domain are included in Table 6 for reference.

Table 6

Four Domains of Concussion Signs and Symptoms

Physical	Cognitive	Emotional	Sleep
Headache	Feeling slowed down	Irritability	Trouble falling asleep
Nausea	Feeling mentally "foggy"	Sadness	Sleeping more than usual
Vomiting		Nervousness	
Balance problems	Difficulty concentrating	Feeling more emotional	Drowsiness
Dizziness			
Fatigue	Difficulty remembering		
Sensitivity to light			
Sensitivity to noise			
Numbness or tingling			
Visual Problems			

Children who reported more symptoms scored lower on neurocognitive measures of verbal memory, visual motor speed, reaction time, and impulse control compared with children who reported no symptoms. There was no difference in visual memory, or cognitive efficiency, between children who reported symptoms and children who reported no symptoms. See Table 7 for comparison of specific neurocognitive domain scores pertaining to symptom reporting.

Table 7

ANOVA Results for Neurocognitive Scores and Number of Concussion Symptoms for Children Who Report Symptoms of a Concussion and Those Who Do Not

ImPACT Domain	Mean Square	F	Significance*
Verbal Memory	520.42	5.36	0.02*
Visual Memory	372.65	2.25	0.13
Visual Motor	183.68	5.71	0.02*
Reaction Time	0.05	4.34	0.04*
Impulse Control	166.80	3.82	0.05*
Cognitive Efficiency	.06	2.77	< .01*
Total Concussion Symptoms	312.063	16.023	< 0.00*

Note: * denotes significance, $p < .05$

Chapter Five: Discussion

Summary of Findings

The purpose of this study was to investigate risk factors that may be associated with low initial scores on the ImPACT test of participants in the pediatric population without a current concussion. To discuss the findings of this research study, each variable was evaluated in terms of the research questions, using the initial hypothesis and current literature. The findings will be followed by clinical implications, limitations, and directions for future research.

Previous concussion

It was hypothesized that children who have had a previous concussion would be more likely to perform statistically low on initial neurocognitive tests (ImPACT) and will report more symptoms, compared with children who have not endured a previous concussion. This hypothesis was not supported. Between-subjects' analyses indicated no difference in neurocognitive scores in most areas; the only domain in which a significant finding was found was in visual motor speed tasks, in which children who had previously sustained a concussion performed lower, compared with children with no prior concussion history. This finding is consistent with current research on concussion which indicates that a full recovery is expected. Thus, when recovery is reached, a child who has previously sustained a concussion and is taking a new baseline assessment should obtain initial scores that are truly his or her personal baseline without residuals from a previous, but healed, concussion. Moreover, having experienced a previous concussion is not associated with lingering symptoms. Therefore, these results converge with current research on concussion recovery, and extends it to the 10-14 age range. Importantly, the children in this study who met criteria for a past concussion sustained only one known past concussion. At the 3rd International Conference on Concussion in 2008 (McCrory et al., 2009) the Panel initially recognized a plethora of modifying factors which exist in concussion management which may include previous concussion and applied this broadly to children ages 10 to 18. Although research supports the idea that repeated concussions over time is a risk factor for repeated concussions with "progressively less impact force or slower recovery after each successive concussion" (McCrory et al., 2009), this study supports the notion that recovery is expected when youths 10-14 experience a concussion.

Attention-deficit hyperactivity disorder (ADHD)

It was hypothesized that children with a previous diagnosis of attention-deficit hyperactivity disorder (ADHD) would be more likely to perform statistically low at baseline on neurocognitive tests compared with children who did not have a previous diagnosis of ADHD. This hypothesis was supported. Between-subjects' analysis indicated that children with a previous diagnosis of Attention Deficit-Hyperactivity Disorder (ADHD) performed significantly lower on most neurocognitive measures, except on the measures of impulse control.

This finding was interesting because impulsivity is a hallmark of ADHD (APA, 2013). However, examination of the tasks that comprise the impulse control composite of the ImPACT provides further clarification into this finding. The impulse control composite is derived from obtaining the omissions of one subtest on an interference task (X's and O's) and the commissions of another subtest (color match). On the other hand, the reaction time score is derived from the number of correct scores on the interference task (X's and O's), the number of correct scores on a color match task, and the number of correct scores on a symbol match task. The cognitive efficiency index measures the interaction between accuracy and speed on the Symbol Match test (ImPACT, 2017). Therefore, the children with ADHD generally obtained fewer correct scores and performed tasks more slowly but did not make more errors than the non-ADHD group.

One possible explanation for this finding is that the current study did not differentiate between different subtypes of ADHD; nor does the demographic section of the ImPACT when it asks caregivers if the child has a history of the disorder. Predominant features of ADHD, especially in children with Inattentive type or Combined type, are difficulty sustaining attention, being easily distracted, forgetting easily, and difficulty paying attention to details. Characteristics of hyperactivity and impulsivity include fidgeting often, leaving chair often when sitting is expected, climbing/running/talking excessively, and acting on the go. The testing items on the ImPACT that would be sensitive to ADHD correlate more closely to inattentive features rather than impulsive/hyperactive features. For example, a child who has difficulty sustaining attention and responds more slowly will likely perform worse on tasks of speed and efficiency, although the child may not necessarily make more mistakes on individual items because the nature of the test purports to be short, interesting, and game-like. However, a child may respond slower because he or she is engaging in distractible behaviors during timed measures such as fidgeting or spinning in his or her chair. Furthermore, the domain "impulse control" may be misleading when considering it in the context of ADHD as a modifier because the ImPACT's demonstration of impulse control is purely in relation to commissions and omissions, which is often a result of right-left hand confusion when taking the test, not to diagnostic features of impulsivity.

It was further hypothesized that children with previously diagnosed ADHD will report more symptoms at baseline, compared with children with no previous diagnosis of ADHD. This hypothesis was also supported. Children with ADHD reported significantly more nonspecific concussion symptoms at baseline (i.e., headaches, dizziness, irritability), compared with children with no history of ADHD. This finding supports previous research, such as one study by Nelson et al. (2016) which evaluated the relationship between ADHD, LD, concussion history and performance on standard concussion assessment measures in high school and collegiate athletes. The results of the Nelson et al. study indicated that individuals with ADHD reported more baseline symptoms in athletes with no history of concussion, so the current findings extend this research to a younger cohort of athletes. The study found significance ($p < 0.001$) in the symptoms of difficulty concentrating, fatigue, trouble sleeping, difficulty remembering, and balance problems in the ADHD group. Although the current study did not differentiate between symptoms and severity, the data support the notion of the non-specificity of concussion symptoms, including the number of the symptoms associated with concussion often exist pre-morbidly or comorbidly in children with ADHD.

Learning Disability (LD)

It was hypothesized that children ages 10-14 with a pre-existing learning disability (LD) would be more likely to perform statistically low at baseline on neurocognitive tests compared with children who did not have a pre-existing learning disability. The findings supported this hypothesis in all neurocognitive measures except reaction time. Similarly, in a study by Zuckerman et al. (2013) which examined baseline neurocognitive scores from the ImPACT in high school athletes with attention deficit disorders and/or learning disability, adolescents with a LD performed significantly lower on measures of verbal memory, visual memory, and visual motor speed, and displayed higher reaction time. Further, in another study which evaluated the relationship between ADHD, LD, concussion history and performance on standard concussion assessment measures in high school and collegiate athletes (Nelson et al., 2016), LD was associated overall with lower baseline performance across neuropsychological measures. Therefore, the current study is consistent with current research on the relationship between initial neurocognitive testing and LD populations in the younger pediatric population.

It was further hypothesized that children with a pre-existing learning disability would report more symptoms at baseline compared with children with no learning disability. This hypothesis was not supported because children with a previously identified learning disability did not report any more symptoms at baseline than children without a previously identified learning disability. This is consistent with the results of athletes in the previously discussed study by Nelson et al., 2016, which also found higher symptom reporting in the ADHD group, but not in the LD group. It is hypothesized that this discrepancy may be due to the behavioral symptoms that are associated with ADHD; these include difficulty sustaining attention, which correspond more closely to the nonspecific symptoms in concussion, i.e. difficulty concentrating, that do not necessarily occur in LD populations. Thus, there appears to be more overlapping characteristics of ADHD which are like concussion symptoms. In contrast, in the Zuckerman et al. study (2013) which focused on high school athletes, children with LD endorsed more symptoms. Possible explanations for this discrepancy are gender and age as confounding variables. More females (23 – 29%) were represented in the Zuckerman et al. study compared with the Nelson et al., study, which was made up of primarily male athletes. Females may be more likely to report symptoms in general, compared with males.

Psychiatric condition (depression/anxiety)

It was hypothesized that children with a pre-existing psychiatric condition (anxiety/ depression) would be more likely to perform statistically low at baseline on neurocognitive tests compared with children who did not have a pre-existing psychiatric condition. This hypothesis was not supported. However, although the sample size was large overall (N = 734), only 12 children had a reported psychiatric condition in the sample. Therefore, this data should be interpreted with caution and further research should replicate this condition. Although symptoms of anxiety and depression have been shown to reduce a person's cognitive resources, (Levin et al., 2007), the children in the current study with a previous diagnosis did not demonstrate reduced cognitive capacities on neurocognitive testing. This contrasts with a study by Bailey et al. (2010), which found a significant relationship between psychological distress and baseline testing of male collegiate football players. Therefore, age and the severity of the premorbid or co-existing anxiety/depression may have contributed to this discrepancy. Perhaps the younger children, even those with a history of anxiety and depression, do not have the same degree of distress, adjustment difficulties, and lack of coping skills that older adolescents confront. The results of the current study are more comparable with a small study (20 individuals with a history of depression) by Cicerone and Kalmar (1997), which examined the interaction of pre-existing depression at baseline, in which the results were not statistically significant.

It was further hypothesized that children with a history of anxiety or depression would report more symptoms at baseline, compared with children with no history of anxiety or depression. The findings supported this hypothesis. Although the condition group was small, the significance was high, indicating that children with premorbid or current depression or anxiety tend to report many symptoms which fall under the umbrella of symptoms that are associated with concussion. Possible symptoms of anxiety and depression which coincide with the constellation of symptoms associated with concussion include headaches, fatigue, mental fogginess, anxiety, crying, irritability, sadness, drowsiness, sleeping, and difficulty sleeping.

Symptom-reporting

Although not part of the original hypothesis, the effect of symptom reporting in general at baseline was examined, in pursuit of the question, "Is the number or severity of concussion-related symptoms reported at baseline a risk-factor for obtaining low baseline scores?" The data supported this hypothesis in most domains, except in the areas of visual memory or cognitive efficiency. It seems that it is not necessarily the existence of modifying conditions themselves that may lead to poorer scores with some of the conditions examined, but the endorsement of symptoms that play a key role in neurocognitive testing. For example, in the case of a previous concussion or previous diagnosis of depression/anxiety, it may not be the diagnosis itself that may lead to lower neurocognitive scores, but the number and severity of symptoms that a child is currently endorsing that is associated with poorer performance. Please refer to Table 5 for a breakdown of the 22 symptoms addressed on the ImPACT. The notion that symptoms that are commonly associated with concussion are nonspecific is important to underscore, because children who are endorsing a multitude of symptoms at baseline can be experiencing many different medical and/or psychological complaints.

Limitations

This study had several limitations. Although the sample size was large, it was derived from a specific demographic population. The study was retrospective, and the sample consisted of children whose parents willfully brought them to a private testing center and were financially able and willing to obtain preseason testing for their children. This differs from other baseline data studies of older children and young adults, wherein baseline testing was likely mandated to play a certain contact sport. A second limitation of this study concerns age paradigms. The data set was obtained from children ages 10-14, who participated in baseline testing using the

ImPACT. Recently (2016), a pediatric version of the ImPACT was introduced for use with ages 5-12. Similarly, the most recent Consensus Statement (McCrory et al., 2017) advises that child and adolescent concussion guidelines refer to persons ages 18 and younger, with "child-specific paradigms for SRC should apply to children aged 5-12 years, and adolescent-specific paradigms should apply to those aged 13-18 years" (McCrory et al., 2017). The current study utilizes a pre-teen age group of 10-14, which overlaps both groups. However, the novelty of this was that it examined a younger cohort of athletes, compared with other studies. Another limitation of the present study was that it did not discriminate between subtypes of ADHD, LD, depression, or anxiety, but rather grouped them into different categories. Finally, the psychiatric sample in this study was very small compared with the sample size, although this may be representative of both the age group and the population of student athletes.

Clinical Implications

Overall, this study supports existing research on concussion with regard to pediatric population, baseline testing, and modifiers, but with a younger pre-adolescent age group. Perhaps the most surprising and important finding of this study was the importance that baseline symptoms play, either independently or interdependently of pre-existing conditions, on initial neurocognitive testing.

Considering previous concussion as a potential modifier, the present study finding is consistent with current concussion research which indicates that a full recovery, including resolving of symptoms, is a general expectation of concussion course of recovery. A recent study by Brooks et al (2013) found that adolescent athletes, ages 13-17 who had sustained at least two previous concussions did not demonstrate significantly worse performance on the ImPACT neurocognitive battery at baseline, compared with adolescent athletes who did not have any prior concussions, although they endorsed a higher number of baseline symptoms. The adolescents in this sample had no pre-existing conditions such as LD or ADHD. The current study found similar results with the younger age group of children ages 10-14. This implies the notion that, like the older adolescent and young adult athletes, having experienced one, or possibly more than one, previous concussion does not predict lower neurocognitive performance on future initial (baseline) testing scores. Second, it implies the idea that it is the endorsement of symptoms at the time of testing, in either quantity or severity, that is more predictive of lower neurocognitive scores.

The current study supported ADHD as a modifier in baseline testing with a younger population. Similar results were found in a study by Zuckerman et al. (2013), which examined baseline neurocognitive scores from the ImPACT in high school athletes with attention deficit disorders and/or learning disability. Specifically, participants in the Zuckerman et al. study (2013) with ADHD performed significantly lower in the areas of verbal memory, visual memory, and visual motor speed scores, and performed significantly better on reaction time and impulse control. The implications of these findings provide further support for the need and utility of distinct normative values with special populations such as children with ADHD or LD and extends this to the younger pediatric paradigms.

ADHD as a modifier in symptom reporting at baseline testing in athletes, ages 10-14 years was also supported in this study. This is also consistent with current research, which acknowledges that many of the symptoms commonly associated with the effects of concussion or a mild traumatic brain injury (mTBI) are nonspecific because they may overlap, coincide, or interfere with many other health conditions such as mood disorders, neurological problems, and learning or developmental disabilities (McCrory et al., 2017). Furthermore, similar findings were documented in the Zuckerman et al. study (2013), with high school athletes with ADHD endorsing significantly more symptoms at baseline compared with control groups. This implies the idea that the symptom checklist given routinely as part of the ImPACT during preseason testing has as much, if not more, clinical utility as the neurocognitive portion of the assessment. Without the knowledge that children with pre-existing ADHD are more likely to report more symptoms at baseline, post-injury assessments risk faulty interpretation.

Learning disability as a modifier in pediatric ImPACT baseline scores was supported in the current study, but not as a modifier with symptom-reporting at baseline. Similarly, in a study by Zuckerman et al. (2013) which examined baseline neurocognitive scores from the ImPACT in high school athletes with attention deficit disorders and/or learning disability, adolescents with an LD performed significantly lower on measures of verbal memory, visual memory, and visual motor speed, and displayed higher reaction time. This implies that children with a learning disability are at risk for poorer initial neurocognitive scores, regardless of symptoms experienced at the time of testing. It also highlights the idea that despite the current guidelines recommending the notion that there be no baseline testing in younger populations due to their changing brains, there may be utility for baseline testing in special populations, given the reduced applicability of norms to these individuals. In contrast, in the Zuckerman et al. study (2013), which focused on high school athletes and on children with LD endorsed more symptoms. Therefore, age may play a role in symptom acknowledgement, but future studies need to replicate these results.

Psychiatric conditions (anxiety/depression) as a modifier in pediatric baseline neurocognitive scores was not supported in this study. The results of the current study contrast with a research study which examined the effect of psychological distress on baseline functioning in 17 to 19-year-old male football players (Bailey et al., 2010), which found significant interactions between numerous psychiatric conditions and baseline concussion neurocognitive performance, such as anxiety, depression, substance abuse, and suicidal ideation. The implications are that age and the severity of the premorbid or co-existing anxiety/depression may modify the effect that the diagnosis has on preseason testing. Perhaps the younger children, even those with a history of anxiety and depression, do not have the same degree of distress, adjustment difficulties, and lack of coping skills that older adolescents confront. The current study did, however, support increased symptom reporting with this population, further underscoring the idea that it may not be the condition itself that acts as a modifier, as much as it is the symptoms that may present concurrently, which are often like the nonspecific symptoms associated with concussion.

Finally, when symptom reporting was examined on its own as a modifier in initial testing, there was strong evidence that the number and severity of symptoms reported was highly correlated with poorer performance. These findings suggest that in the pediatric population of 10-14-year-olds, it is likely that children with LD and ADHD will perform significantly worse on neurocognitive initial concussion testing. Further, the findings suggest that independent of premorbid LD, ADHD, anxiety, depression, and previous concussion, a child who endorses more symptoms at baseline will probably perform worse on neurocognitive measures. Last, this study implies that children with pre-existing ADHD, anxiety, or depression may be more likely to endorse more symptoms at baseline, which may be characteristic of the pre-existing condition or not and will likely demonstrate poorer neurocognitive initial scores compared with the children without a pre-existing condition.

Directions for Future Research

Concussions are a complex phenomenon that experts are only beginning to understand as they continue to wrestle with an appropriate definition that appropriately encapsulates the specific events that occur in this type of traumatic brain injury. Understanding the best practice in the identification, diagnosis, neuropathology, assessment, and treatment of concussion is equally challenging as more research continues to develop and unfold in this arena. Furthermore, understanding the key differences that present between concussions in children/adolescents and adults is complicated because their brains are undergoing critical growth. Youth who have an established diagnosis of learning disability (LD), Attention Deficit-Hyperactivity Disorder (ADHD) and depression or anxiety or concussion history present with a diverse and unique set of characteristics that may drive academic interventions through IEPs and 504 accommodation plans and alter patterns in baseline concussion assessments. The most recent Consensus Statement (McCrory et al., 2017) recognizes the scarcity of sports related concussion research that is specific to younger children and needs to be addressed as a priority moving forward. The diagnosis, treatment, and expectations for recovery, return to play, and return to learn decisions in the pediatric population diagnosed with a concussion who have a pre-existing condition may need to be adjusted and monitored differently or more carefully from with children who do not have pre-existing condition.

The importance of modifiers has already been demonstrated in routine baseline administrations for concussion screening because these factors may indeed influence the neurocognitive scores of a young athlete in the absence of a concussion (Zuckerman et al., 2013). Several modifying factors have been associated with the prevalence of sustaining a concussion and the possible subsequent occurrence of post-concussion syndrome. Known modifying factors in concussion include a previous concussion as well as pre-existing conditions such as attention-deficit/hyperactivity disorder (ADHD), learning disability (LD), mood disorders (anxiety/depression), migraine, and sleep dysfunction (McCrory et al., 2009; McCrory et al., 2012). However, future research needs to include children as young as ages 5-12 to examine differences among baseline testing with and without modifying conditions to strengthen and support baseline testing in pediatric populations.

Future research on baseline testing with special populations such as in this study, would be beneficial with the new norms of the Pediatric ImPACT which specifically addresses the 5-12 years age group. Although the use of pre-season baseline testing has documented and established for quite some time (Barth, 1989), its clinical utility remains unclear and continues to be examined (Davis et al, 2017; McCrory et al., 2017). The current guidelines purport that baseline testing can be a useful, although not mandatory, tool in assessment of concussion management. Future research on this topic may include identifying certain conditions at baseline which can predict certain symptoms or neurocognitive deficits after sustaining a concussion. Future studies should replicate initial testing in this age group and specifically examine which symptoms, and to what extent, are correlated with poorer performance on initial concussion testing. With regard to ADHD and anxiety/depression symptom reporting, further study is necessary to determine what other factors may be contributing to higher symptoms reporting at baseline; for example, if a third variable is present, or if, as suggested by the current study, it is the non-specificity of the concussion symptoms that tend to overlap with characteristics attention problems, anxiety, and depression. Bonfield et al. (2013) investigated the impact of ADHD diagnosis on the recovery from closed mild traumatic brain injury in youths ranging from ages 6-17 years, and the results suggested the possibility that these children may be more disabled than their nondisabled peers at baseline, which would make them appear more disabled during recovery as well. They also acknowledge the issue of a possible third confounding variable of SES because low SES is associated with higher rates of ADHD (Bonfield et al, 2013). This acknowledgement is in line with the emerging data from the most recent Consensus on Concussion in Berlin (McCrory et al., 2017), which indicates that ADHD appears to be predictive of lower baseline scores in children, but not of recovery timelines. Therefore, future studies need to explore further the role of spurious variables in pediatric initial testing for concussion.

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