ImPACT™ PERFORMANCE OF HIGH SCHOOL STUDENT ATHLETES WITH ADHD

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DEDICATION

I would like to thank the members of my Thesis Committee, the faculty and staff of the UT Southwestern Department of Rehabilitation Counseling, the research staff of the University of Texas at Arlington, and the participants for their respective contributions.

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by

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THESIS

Presented to the Faculty of the School of Health Professions

The University of Texas Southwestern Medical Center

Dallas, Texas

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF REHABILITATION COUNSELING

Abstract

BACKGROUND: To date, two studies demonstrate that adolescents with ADHD tend to perform poorer on the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT; Lovell, 2013) at baseline than do adolescents without ADHD at baseline (Elbin et al., 2013; Zuckerman, Lee, Odom, Solomon, & Sills, 2013). In an effort to replicate and extend these studies, the baseline and immediate post-concussion performance of high school athletes with and without ADHD were evaluated to identify potential differences between groups on the ImPACT's domains.

SUBJECTS: Student athletes were recruited from a private high school. Baseline testing was conducted biannually to establish pre-injury/baseline levels of individual participants. Thirty-eight students with ADHD and a matched control group of thirty-eight students without ADHD were used to test the first hypothesis. Twenty-three students with ADHD and a matched control group of twenty-three students without ADHD who sustained a concussion were used to test the second and third hypotheses. Additional analyses were performed on data from four student athletes with ADHD who sustained a concussion.

METHOD: Data were used from a larger study conducted by a large public metropolitan university. Variables included demographic information and the ImPACT. All data were stored on an encrypted computer or in a locked file cabinet.

RESULTS: Independent samples *t*-tests revealed significant differences between athletes with ADHD and non-ADHD athletes at baseline on the Impulse Control ($t_{(74)} = 2.73, p < .01$) and the Total Symptoms ($t_{(74)} = 2.63, p < .05$) scores of the ImPACT. A multivariate analysis of variance (MANOVA) was conducted on data from two time periods. A statistically significant difference ($F(6, 39) = 2.86, p = .02$; Wilks' $\Lambda = 0.694$; $\eta^2 = .31$) in ImPACT performance was found between non-concussed athletes with ADHD tested at baseline and concussed athletes without ADHD tested within 72 hours of injury (M = 1.83 days). Further analysis using independent samples *t*-tests found that athletes with ADHD at baseline performed significantly better than concussed athletes without ADHD tested within 72 hours of injury, on the following composites: Verbal Memory ($t_{(44)}$= 2.25, $p < .05$), Visual Motor Speed ($t_{(44)}$= 2.33, $p < .05$), Reaction Time ($t_{(44)}$= -3.42, $p < .01$), and Total Symptoms ($t_{(44)}$= -3.52, $p < .01$). No significant between-group differences were found on the Visual Memory or Impulse Control composites of the ImPACT. DISCUSSION: These findings indicate that administration of the ImPACT to individuals with ADHD is appropriate. At baseline, both groups performed similarly on Verbal Memory, Visual Memory, Visual Motor Speed and Reaction Time. However, the overlap in ADHD and concussion profiles on Impulse Control and Visual Memory warrant caution in the clinical interpretation of the ImPACT profiles of individuals with ADHD. Nevertheless, these findings suggest that the overall use of normative data within an ADHD population is appropriate, and baseline testing has values for athletes with ADHD.

Keywords: ImPACT™, ADHD, sport-related concussion.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION ... 8

CHAPTER TWO: REVIEW OF THE LITERATURE ... 11

Traumatic Brain Injury ... 11

Sport-Related Concussion ... 12

ADHD ... 20

Commonalities Across SRC and ADHD ... 27

ImPACT Performance for Athletes with ADHD ... 27

Summary and Research Aims ... 30

CHAPTER THREE: METHOD ... 33

Participants ... 33

Procedures ... 34

Measures ... 35

CHAPTER FOUR: RESULTS ... 37

Descriptive Statistics ... 37

Results of Hypothesis Testing ... 38

ADHD Concussion Case Study ... 39

CHAPTER FIVE: DISCUSSION ... 41

Hypothesis 1 ... 41

Hypotheses 2 and 3 ... 43

ADHD Concussion Case Study ... 44

Limitations and Future Research ... 45

REFERENCES ... 47

LIST OF TABLES

TABLE 1 ………………………………………………………..……………………….. 59

TABLE 2 ……………………………………………….…………………………….. 60

TABLE 3 ……………………………………………..…………………………….. 61

TABLE 4 ……………………………………………….…………………………….. 62

TABLE 5 ……………………………………………….…………………………….. 63

TABLE 6 ……………………………………………….…………………………….. 64

TABLE 7 ……………………………………………….…………………………….. 65

TABLE 8 ……………………………………………….…………………………….. 66

LIST OF ABBREVIATIONS

SRC – Sport related concussion

ImPACT – Immediate Post-Concussion Assessment and Cognitive Test

ADHD – Attention-Deficit/Hyperactivity Disorder

WCST – Wisconsin Card Sorting Test

WAIS-IV – Wechsler Adult Intelligence Scale, 4th edition

WISC-IV – Wechsler Intelligence Scale for Children, 4th edition

TOVA – Test of Variables of Attention

WISC-IV – Wechsler Intelligence Scale for Children, 4th edition

TBI – Traumatic brain injury

CDC – Centers for Disease Control

WMI – Working Memory Index

PSI – Processing Speed Index

CHAPTER ONE

Introduction

Sport related concussion (SRC) has become a serious health concern in recent years, primarily due to the associated impairments in athletes' daily functioning. The complexity in SRC presentation and minimal information about SRC has historically made concussion assessment a challenge for health care providers. However, the accumulation of SRC research and its dissemination to providers has improved the accuracy of SRC assessment and diagnosis. Currently, a comprehensive SRC assessment includes a physical examination and medical history, evaluation of concussion-related symptoms, postural control, and neurocognitive and motor deficits (Broglio, Macciocchi, & Ferrara, 2007b).

The neurocognitive component of SRC assessment often involves the use of computerized neurocognitive assessment tools. The Immediate Post-Concussion Assessment and Cognitive Test (ImPACT; Lovell, 2013) is the most common of the computerized neurocognitive test batteries used in United States high schools (Meehan et al., 2012). In addition to evaluation of neurocognitive functioning, the ImPACT gathers demographic and symptom information. The neurocognitive test battery includes an assessment of attention span, working memory, sustained and selective attention, response variability and non-verbal problem solving. However, factors such as age, gender, learning disability and Attention-Deficit/Hyperactivity Disorder (ADHD) can contribute to differences in neurocognitive performance unrelated to concussion (i.e., systematic sources of error), and require cautious interpretation when referencing normative data. In recent years many athletic teams have adopted baseline or pre-season computerized testing. Baseline testing, conducted prior to the competitive season, allows for a more individualized assessment and more accurate determination of changes in cognitive functioning post-concussion (Broglio et al., 2014).

Although use of baseline testing is recommended, it is not a requirement. Further, untangling the symptoms of concussion from those of ADHD may be a challenge. Overlap of SRC symptoms and ADHD symptoms poses a potential barrier to valid SRC assessment and interpretation. Many ADHD symptoms resemble the neurocognitive deficits associated with concussion (McCrory et al., 2013). Just as concussed athletes display deficits on ImPACT testing, individuals with ADHD may display similar deficits.

Evidence supports that individuals diagnosed with ADHD do perform poorer than those without ADHD on both pen-and-paper and computerized neuropsychological testing. These tests require skills such as learning, working memory, processing speed, attention and impulsive control that correspond with the components of functioning measured on the ImPACT's six primary modules (Lovell, 2013). Since these tests were the predecessors of the ImPACT, adolescents with ADHD would be expected to demonstrate similar deficits on these portions of the ImPACT. In fact, two studies have shown that adolescents with ADHD tend to perform poorer on the ImPACT at baseline than do adolescents without ADHD at baseline (Elbin et al., 2013; Zuckerman, Lee, Odom, Solomon, & Sills, 2013). Additionally, high school adolescents with ADHD had a significantly higher likelihood of producing an invalid test performance on the ImPACT compared with students who did not have ADHD (Schatz, Moser, Solomon, Ott, & Karpf, 2012).

Given that adolescents with ADHD generally seem to exhibit poor baseline performance on the ImPACT (Lovell, 2013), differentiating concussion from fundamental ADHD is challenging. This study aims to determine the specific ImPACT domains on which adolescents with ADHD exhibit deficits.

CHAPTER TWO

Review of the Literature

Traumatic Brain Injury

Traumatic brain injury (TBI), although a heterogeneous phenomenon, is defined as an "alteration in brain function, or other evidence of brain pathology, caused by an external force" (Menon, Schwab, Wright, & Maas, 2010). The standard method for identifying the severity of TBI is the Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974), which assesses an individual's basic motor and verbal skills (Semrud-Clikeman, 2001). High scores on the GCS (13-15) are classified as "mild" TBI (mTBI); scores of 9-12 are considered moderate TBI, and scores below eight are within the "severe" range (Semrud-Clikeman, 2001). The majority (80-90%) of TBIs are mild, and the term "mild TBI" is often used interchangeably with the term "concussion" (Halstead & Walter, 2010).

A more recent definition of concussion was provided by the Concussion in Sport Group (CISG). The CISG defines concussion as a "complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (McCrory et al., 2013, p. 1). It has also been described as the "clinical syndrome of neurocognitive or behavioral dysfunction resulting from a biomechanically induced alteration of brain physiology" (Giza & Kutcher, 2014b, p. 1546). In the remainder of this paper, concussion will be used to describe this syndrome.

Signs and symptoms. A loss of consciousness (LOC), although a potential symptom of TBI, is not necessary for diagnosis of concussion. In fact, the majority (90%) of individuals who sustain concussion do not lose consciousness (CDC, 2012); however, a concussed individual who is awake may still be disoriented (Halstead & Walter, 2010). Nevertheless, Cantu (2001) noted the multifaceted nature of concussion symptomatology, and included LOC, posttraumatic amnesia (PTA) and other post-concussion signs or symptoms in his discussion of post-concussion symptoms. Notably, the presence of LOC and PTA has also been associated with an extended recovery time (Levin, 1985). In many cases, however, the symptoms of concussion are subtle, and diagnosis is largely dependent on self-reported and observed symptoms in the absence of objective biomarkers such as structural lesions on standard neuroimaging (Kirkwood & Yeates, 2012).

Self-report symptoms include the immediate, acute symptoms experienced within minutes to hours post-concussion and persistent symptoms that can last anywhere from three to twelve (or more) months in some cases. The most common acute symptoms of concussion include headache, nausea, dizziness, confusion, attention difficulties, and behavioral changes; the most common persistent symptoms include headache, dizziness, memory impairment, irritability, attention and concentration problems, depression, and anxiety (Giza & Hovda, 2014a).

Piland, Motl, Guskiewicz, McCrea and Ferrara (2006) conducted a factor analysis of concussion symptoms. Their findings suggest that concussion symptomatology encompasses three latent clusters of symptoms: somatic symptoms, neurobehavioral symptoms, and cognitive symptoms. The somatic symptoms related to concussion include headache, nausea and balance problems. Neurobehavioral symptoms include sleeping more than usual, drowsiness and fatigue. The cognitive symptoms of concussion may be described as feeling “slowed down” and “in a fog,” and also include difficulty with concentration.

Sports-Related Concussion

Sports-related concussion (SRC) is a current public health concern (Halstead & Walter, 2010; McCrory et al., 2013). Although SRC research is still a relatively new field, research on SRC in adolescents is particularly limited (Theye & Mueller, 2004). Guskiewicz and McLeod

(2011) reviewed adolescent SRC literature and discuss the consequences of SRC in high school athletes. Adolescent athletes are required to refrain from physical and cognitive activity following a concussion. The cognitive rest required after a concussion may include limited mental exertion in activities such as computer work and school attendance (Guskiewicz & McLeod, 2011). Although the long-term consequences of sports-related concussion remain unclear, clinicians are advised to err on the side of caution to ensure the health, wellbeing and quality of life of athletes, particularly adolescents (Theye & Mueller, 2004).

Mechanism. A direct impact to the head, such as a helmet-to-helmet collision in football, can cause a SRC. However, a SRC can also result from a collision or fall that causes an "impulsive" force to the head, otherwise known as "whiplash" (Kelly & Rosenberg, 1997; McCrory et al., 2013). In either case, physical linear and/or rotational forces act upon the head, causing the brain to accelerate and decelerate (Kelly & Rosenberg, 1997).

Pathophysiology. Ultimately, the disruption of the brain's cellular processes results in cellular or physiological functional injury (e.g., ionic shifts, metabolic change, impaired neurotransmission) or microstructural injury (Giza & Kutcher, 2014b). The pathophysiological response to concussion, termed *neurometabolic cascade,* results in acute pathophysiological effects: mechanoporation, ionic flux, and an indiscriminate release of glutamate.

Mechanoporation refers to the transient membrane permeability of the neuron. The depolarized neurons trigger a widespread release of glutamate; consequently, ionic pumps deplete their intracellular energy stores. The result is a relative energy crisis that occurs simultaneously with a decrease in cerebral blood flow. Termed "uncoupling." Consequently, metabolic functioning declines for several days as damaging free radicals are generated and metabolic pathways shift. During the following seven to ten days of impaired metabolism there may in fact be a window of increased biological vulnerability to repeated injury (Giza & Kutcher, 2014b).

Given this window of vulnerability, early diagnosis of a SRC is essential. A concussed athlete who returns to play while still showing symptoms is at higher risk of repeated injury and potential negative long-term consequences (Lau, Collins, & Lovell, 2012). The International Consensus on Concussion in Sport recognizes the potential risks of returning to play before a full recovery and instructs concussed athletes to refrain from play until asymptomatic (McCrory et al., 2013).

Reported incidence. Reports of SRC in high school athletes have increased over time. According to the Centers for Disease Control (2011), the reported incidence of SRC increased over 60% in children and adolescents over the last decade. Across all high school sports, an estimated 2.4-2.5 concussions occur for every 10,000 athletic exposures, which includes practices and games (Guerriero, Proctor, Mannix, & Meehan, 2012). According to the National high school sports-related injury surveillance study (Comstock, Collins, Corlette, & Fletcher, 2012), SRC accounts for up to 25% of injuries in competition and 17% in practice, overall 21%; football accounts for approximately half, followed by girls' soccer (up to 8%) (Guerriero et al., 2012). The growth in SRC diagnosis may be related to a prior lack of knowledge about concussion; as knowledge increases, health professionals have become better equipped to identify and diagnose concussion. Conversely, McCrea, Hammeke, Olsen, Leo & Guskiewicz (2004) found that only 47.3% of high school football players who endorsed sustaining a concussion during season on a self-report questionnaire reported the event.

Assessment of SRC. A multidimensional approach has been recommended to assess and manage SRCs. This multi-faceted approach consists of assessing concussion related-symptoms, a physical examination and medical history, and measuring of neurocognitive and motor deficits/postural control (Broglio et al., 2007b). To date, all 50 states have passed laws to improve care to concussed athletes. Depending on the state, varying health care professionals (e.g. certified ATs, physicians, physician assistants, nurses, etc.) can assess and diagnose SRC using one or more of these recommended clinical components (Guerriero et al., 2012; Lau et al., 2012). Assessments can be divided into acute/sideline or clinic based assessments.

Computerized neurocognitive assessment. After the clinical examination and assessment of self-reported symptoms, computerized neurocognitive tests are an efficient tool for concussion assessment and management. The use of computerized neurocognitive tests by ATs has risen from 15% in 2005 to 44% in 2013 (Lynall et al., 2013). Approximately 40% of United States high schools currently use computerized testing in concussion management (Meehan, d'Hemecourt, Collins, Taylor & Comstock, 2012). Computerized neurocognitive assessment is advantageous in many areas that traditional neurocognitive assessment lacks. For example, computerized neurocognitive tests can be administered serially to detect mild changes in cognitive functioning. Although changes can be detected between baseline and post-concussion testing, subtle decline in cognition associated with concussion is better detected using serial administration. The nuances of conventional neuropsychological testing (i.e., pen-and-paper) present limitations to multiple administrations of tests, such as supervision, manual scoring and interpretation. Computerized neurocognitive testing minimizes these barriers and can be conducted on a wider scale (Collie et al., 2003).

One example of a computerized neurocognitive test battery is the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT; Lovell, 2013). The ImPACT is currently used in 93% of the United States high schools employing computerized testing (Meehan et al., 2012). The ImPACT is a 25-minute evaluation that gathers demographic and symptom information and assesses neurocognitive functioning. The neurocognitive test battery includes an assessment of attention span, working memory, sustained and selective attention, response variability and non-verbal problem solving tasks. The test consists of six modules and two delayed tasks that contribute to four neurocognitive indices (see Table 1). The ImPACT has automated invalidity calculations that contribute to its internal measure of effort; one score is termed Impulse Control. The ImPACT provides a sixth score from a symptom scale based on the presence and severity of concussion related symptomology. In terms of the ImPACT's psychometric properties, test-retest reliability coefficients (.23 to .88) are variable; processing speed has the highest reliability and verbal memory has the lowest reliability coefficient. Concurrent validity coefficients (.20 to .88) are also variable (see Method section for additional information). However, the sensitivity and specificity of the ImPACT range from 79.2% to 94.6% and 69.1% and 97.3%, respectively (Resch, McCrea, & Cullum, 2013b). Although there are limitations to the test-retest reliability and validity, the ImPACT provides a standardized, empirically based method for tracking symptoms and recovery of concussed athletes. Health care providers can then use information from the ImPACT as additional information in the return-to-play decision-making process (Lovell, 2013).

Testing Sequence. Although there is some disagreement about its validity (Randolph, 2011), in recent years many athletic teams have adopted baseline or pre-injury testing with computerized tests. Baseline testing is conducted prior to the competitive season and should consist of a thorough history (including concussion symptoms), physical and neurological evaluations, measures of motor control, and neurocognitive function (Broglio, et al., 2004). Although limited data exists regarding a timeline for re-administration of baseline testing, the

National Athletic Trainers' Association Position Statement (2014) recommends that adolescent athletes (and ideally all athletes) complete baseline testing annually (Broglio, et al., 2004). The baseline assessment is used for future individual comparison when athletes are suspected of, or diagnosed with, an SRC.

Normative data for the ImPACT are available for concussed athletes without a baseline assessment. However, factors such as history of concussion, gender, race, ADHD and learning disability may affect the validity of comparing scores with normative data (Covassin, Elbin, Stiller-Ostrowski, & Kontos, 2009). For example, evidence exists to support the presence of a "stereotype threat" occurs when a test taker's awareness of a societal bias towards one's particular subgroup (e.g., African Americans performing poorer on a verbal ability test in a stereotype-threatening condition) (Nguyen & Ryan, 2008). The stereotype threat may affect concussed athletes during neuropsychological testing through a derivative mechanism termed "diagnosis threat" (Silver, 2012). Silver (2012) posits that societal knowledge of the cognitive deficits associated with concussion may cause concussed athletes who are administered neuropsychological tests to "choke," or underperform.

Following a concussion, an athletic trainer, school nurse, team doctor or psychologist administers the ImPACT. The test administrator may follow one of two common test protocols. One protocol, which includes testing the concussed athlete at fixed time points, is an attractive protocol for a research setting. The fixed protocol may include testing the player initially within 48 hours post-injury, again one week post-injury, with continued weekly administration until the athlete's performance returns to baseline. This method tracks the recovery of cognitive functioning and is useful for prospective research; however, as players should not return-to-play until asymptomatic this approach is unnecessarily burdensome and costly. Alternatively, the athlete may be tested only after reportedly asymptomatic. This methodology is ideal in a clinical setting as it reduces practice effects and decreases the cost and time associated with multiple test administrations (Covassin, et al., 2009; Guskiewicz et al., 2004).

Concussion ImPACT profiles. The reliable change index (RCI) is one of multiple methods used to determine clinically meaningful change from one testing occasion to another. The RCI, with respect to the ImPACT, is a calculated reference criterion used to determine meaningful change from baseline performance to post-concussion performance. The RCI takes into account test-retest reliability; the magnitude of change is considered significant only when sufficiently large in proportion to change associated with measurement error (Jacobson & Truax, 1991). Although the standard RCI does not control for other confounding variables, manipulation of the numerator results in *modified* RCIs that can account for variables such as practice effects and measurement error (Collie et al., 2004). Although various models exist to determine clinically meaningful change, each presents a set of advantages and limitations, of which the clinician must be conscious (Resch et al., 2013b).

An example by Hinton-Bayre, Geffen, Geffen, McFarland and Frijs (1999) demonstrates the various advantages and limitations for RCI cut-offs and the relevance of the clinical situation. Practice effects were evaluated in a comparison of rugby players' baseline and post-concussion results with results of a matched control group. Varying RCI cutoffs, determined by more or less conservative inclusion criteria, resulted in varying sensitivity and specificity. Although one particular model resulted in an 88.5% overall classification rate, the authors selected an RCI criterion with an 81% overall classification rate. This criterion resulted in a lower false negative rate, which the authors regarded as more valuable than a lower false positive rate. In this clinical setting, a false negative can result in a player's premature return-to-play. Therefore, the authors chose to err on the side of caution despite the knowledge that a player may be withheld from play longer than necessary (Hinton-Bayre et al., 1999).

Iverson, Lovell and Collins (2003) provide empirical evidence for a specific pattern of concussion results on the ImPACT. When compared to non-concussed athletes (tested twice), concussed athletes were 47 times more likely to demonstrate post-injury declines from baseline on two or more of the five ImPACT composites. However, as a group, recently concussed athletes appear to perform poorer on all of ImPACT's domains. Generally, large changes from baseline to post-concussion scores are observed on verbal memory, reaction time and self-reported symptoms. Medium-to large changes are typically observed on visual memory and processing speed. According to Iverson et al., (2003), impulse control scores are likely to identify test takers who are either sandbagging or do not understand the test instructions; therefore, the impulse control composite score was not included in their model.

Invalidity and sandbagging. The ImPACT identifies invalid profiles and sandbagging profiles (Lovell, 2013). An invalid profile suggests that the test taker's results are not interpretable for any of the following reasons: the test taker did not understand the test, the presence of a learning disorder or ADHD impaired the test taker, cultural or ethnic differences, fatigue or any other external factor that affects performance. Sandbagging, however, is defined as deliberate test-taker malingering. A student athlete with a sandbagging profile may have intentionally performed poorly to set a low baseline score, thereby allowing for any deficits to go undetected during post-concussion testing (Szabo, Alosco, Fedor, & Gunstad, 2013). A potential external motive for student athletes to sandbag at baseline is to ensure a quick return-to-play. It should be noted that the ImPACT has built in "red flags" and validity indicators to help detect sandbagging or otherwise invalid performance. Red flags and validity indicators detect performance at two or more standard deviations below the mean.

Attention-Deficit/Hyperactivity Disorder

The presence of the neurodevelopmental disorder, Attention-Deficit/Hyperactivity Disorder (ADHD), complicates SRC assessment. The Diagnostic and Statistical Manual of Mental Disorders, 5th edition (American Psychiatric Association, 2013) defines ADHD as "a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning and development" (American Psychiatric Association, 2013, p. 59-60). To meet criteria for an ADHD diagnosis an individual must exhibit at least six inattentive symptoms or six hyperactive/impulse symptoms.

Inattentive symptoms can manifest in many ways. For example, an individual may report making careless errors in his/her work, or an observer may note the individual does not listen when spoken to directly. Hyperactive/impulsive symptoms are more observable. For example, symptoms might include blurting out answers before a question is finished or running and climbing in situations where sitting is expected. Additionally, these symptoms must be present for at least six months to a degree that is inconsistent with the individual's developmental level. The symptoms must be present early in the developmental period (before 12 years of age) and cause clinically significant impairment in at least two areas of life, such as social, academic and/or occupational activities. Before a diagnosis of ADHD is made an intellectual disorder or global developmental delay must be ruled out. An ADHD diagnosis must specify the subtype: ADHD Predominantly Inattentive Type, ADHD Predominantly Hyperactive-Impulsive Type, or ADHD Combined Type (American Psychiatric Association, 2013). According to the DSM-5, 5% of children in the United States are diagnosed with ADHD (American Psychiatric Association, 2013); however, the CDC (2013) estimates a less conservative 11% prevalence of ADHD in children aged 4 to 17 years.

Cognitive characteristics of ADHD. Primarily, ADHD is conceptualized as a difficulty with sustained attention. However, overwhelming evidence supports that the deficits in ADHD stem from an overarching construct termed executive function (Baron, 2004). Although various definitions exist, Baron (2004) defines executive functioning as follows:

> … Metacognitive capacities that allow an individual to perceive stimuli from his or her environment, respond adaptively, flexibly change direction, anticipate future goals, consider consequences, and respond in an integrated or common-sense way, utilizing all these capacities to serve a common purposive goal (p. 135).

According to Seidman (2006), executive function appears to encompass four broad factors: working memory, set shifting, response inhibition and execution, and interference control. Furthermore, the processes involved in executive function can be categorized as "cool" or "hot" (Anderson, Jacobs, & Anderson, 2008). The cool processes include the cognitive skills such as abstract thinking and problem solving. Conversely, the hot processes incorporate the affective components of executive function, such as an individual's emotional and subsequent behavioral response to emotions.

Numerous models exist that attempt to explain the component processes of executive functioning. While no single model can avoid the oversimplification of this complex construct, Barkley (1997) developed a comprehensive hybrid model that is generally accepted in the field. This hybrid model builds on four of its predecessors: Bronowski (1977), Fuster (1989), Goldman-Rakic (1995), and Damasio (1995). Each of these individuals developed empirically supported and accepted conceptualizations of executive functioning. However, in the hybrid model, Barkley attends to each of the former models' weaknesses and incorporates their respective strengths.

Behavioral inhibition, Barkley argues, is the key component of executive functioning; behavioral inhibition permits an individual to execute subsequent functions effectively. These functions that are dependent on behavioral inhibition include nonverbal working memory; internalization of speech (verbal working memory); self-regulation of affect; motivation, and arousal; and reconstitution. Barkley describes these functions as private, self-directed, covert behaviors that directly influence the motor system. Thus, internal mental processes have control over observable behaviors. Barkley further explains the motor system's role in executive functioning by conceptualizing how motor control, fluency, and syntax are each responsible for observable, goal-directed behaviors. Motor control, fluency and syntax are dependent on the capacity of an individual to inhibit behavior. As a result, an individual develops the capacity to self-regulate behavior and achieve a goal (Barkley, 1997).

Discernment of the relationship between executive function and ADHD is ongoing. The diversity in presentation of ADHD parallels the various types of deficits in executive functioning (Anderson, Jacobs, & Anderson, 2008; Barkley, 1997; Baron, 2004; Forbes, 1998; Nigg et al., 2005; Seidman, 2006). A subset of individuals with ADHD demonstrates little to no executive dysfunction. However, the acknowledgement of executive function's intricate role in ADHD has substantially developed the conceptualization of the disorder.

Neurological underpinnings of ADHD. Strides in biological research and functional magnetic resonance imaging (fMRI) allow for a better understanding of the neural components of ADHD. Currently, the prefrontal model of ADHD is the accepted explanation of the neural underpinnings to ADHD (Seidman, 2006). The prefrontal cortex (PFC) is responsible for decision making, planning and organizing- processes which are impaired in ADHD. Consistent with the PFC model, structural and functional imaging studies reveal abnormal frontal lobe status in many individuals with ADHD (Max et al., 1998). Furthermore, animals and humans with frontal lobe lesions demonstrate increased impulsivity, distractibility and sometimes, hyperactivity (Seidman, 2006). While neuroimaging consistently reveals PFC abnormalities in individuals with ADHD, other compromised areas of the brain contribute to the underpinnings of ADHD. The caudate, pallidum, anterior cingulate, cerebellum and striatum project to the PFC. These areas are generally smaller in volume in individuals with ADHD and have been hypothesized to contribute to the associated functional impairments (Hynd et al., 1991; Seidman, 2006).

Consistent with the prefrontal cortex model for understanding ADHD, stimulant medications have proven successful in minimizing the symptoms associated with ADHD (CDC, 2013; Seidman, 2006). Although non-stimulant ADHD medication exists, stimulants are the standard ADHD medication, effective in approximately 70% to 80% of children with ADHD (Centers for Disease Control, 2013). The CDC (2013) recommends a combination of medication and behavioral intervention as the most effective treatment for ADHD in children and adolescents, and medication use was the prevailing choice of treatment for 69% of children and adolescents diagnosed with ADHD in the United States in 2011-2012. In the United States, 6.1% of all children ages 4 to 17 reported taking ADHD medications (CDC, 2013). Although stimulants can minimize the symptoms of ADHD, there are possible side effects. The most common side effects include decreased appetite and inability to sleep; extremely rare side effects include the development or exaggeration of a tic, personality changes, cardiovascular problems or sudden death (NIMH, n.d.).

ADHD assessment. The complexities of ADHD assessment and diagnosis are comparable to those of concussion assessment and diagnosis. Multiple sources of information must be considered, such as parent and teacher observations of behavior, parent's report of developmental and behavioral challenges as well as reports of school problems, and a clinical interview including self-reported symptoms and clinical observations (Forbes, 1998). In assessing each of these sources, the clinician must determine that the symptoms are present in multiple settings and are pervasive enough to cause impairment. Furthermore, the clinician must indicate a subtype by identifying a cluster of inattentive symptoms, hyperactive symptoms, or a combination of both types (American Psychiatric Association, 2013, p. 59-60). Additionally, three types of standardized assessment tools are generally used in ADHD assessment: rating scales, continuous performance tests (CPTs), and traditional neuropsychological tests. Specific examples of assessment tools warrant further detailed explanation, as they resemble the types of tests used in concussion assessment. In fact, the ImPACT is derived from the traditional neuropsychological assessment tools.

Traditional neuropsychological assessment. There are a number of tests of attention and executive functioning used in ADHD assessment that are relevant to this study, as they appear to measure constructs similar to those of the ImPACT. Commonly used tests for this assessment are the Stroop procedure (Stroop, 1935), the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay & Curtiss, 1993) and specific subtests of the Wechsler scales (WISC-IV; Wechsler, 2003; WAIS-IV; Wechsler, 2008). Differences in mean scores of individuals with and without ADHD have been consistently documented for each of these tests.

The Stroop procedure. Children and adolescents with ADHD have demonstrated deficits on the Stroop Test (Seidman et al., 2005). The Stroop consists of three separate tasks. The third task is critical because it requires the individual to inhibit an automatic response to the test stimuli; the test taker must name the ink color of a word when the word itself is a different color than the ink (e.g., the word "blue" written in red ink). The third task requires the test-taker to inhibit the automatic tendency to read the written word. This deficit in the self-regulatory function is a core component of ADHD (Peterson et al., 2009).

Wisconsin Card Sorting Test. Children with ADHD often demonstrate deficits on the Wisconsin Card Sorting Test (Seidman et al., 1997). The WCST is a card-sorting task with sorting rules that are withheld from the test-taker; therefore, the test-taker is required to use feedback from the examiner (correct or incorrect) to determine the sorting rules. The test-taker must also discern when the sorting rule has changed and shift his or her mental set. Thus, the test-taker must learn rules over time and use visual working memory to remember what sorting rule was previously correct.

Wechsler Intelligence Scales. Both the WISC-IV and the WAIS-IV contain subtests that have been shown to be sensitive to the deficits in children with ADHD. These subtests make up the Working Memory Index (WMI) and the Processing Speed Index (PSI). Individuals with ADHD perform poorer on WMI and PSI on both the WISC-IV and the WAIS-IV (Halperin, Trampush, Miller, Marks, & Newcorn, 2008; Mayes & Calhoun, 2003; Theiling & Petermann, 2014).

With regards to WMI, individuals with ADHD demonstrate the largest deficits on Digit Span and Arithmetic subtests. Digit Span assesses attention and working memory for auditory information (i.e., digits). The test-taker is read a series of numbers and asked to recite the numbers back to the administrator in three different conditions. The Arithmetic subtest evaluates the appropriate application of basic arithmetic skills to solve orally presented word problems within a timed condition and also relies upon attention and working memory.

With regards to PSI, individuals with ADHD demonstrate the largest deficits on Symbol Search and Coding. Symbol Search assesses one's visual processing speed and visual scanning speed while discriminating between symbols. Coding evaluates the accuracy and speed of a test-taker in transcribing symbols. The test-taker is provided a key and instructed to transcribe corresponding symbols for a list of digits in a timed condition, in order to evaluate working memory and learning capacity.

Computerized cognitive assessment. Continuous performance tests (CPTs) assess inattention, impulsivity and reaction time (Matier-Sharma, Perachio, Newcorn, Sharma, & Halperin, 1995). For example, the TOVA is a computerized test that measures attention, impulsivity, response variability, and reaction time as the child responds to a geometric shape on the computer screen (Leark et al., 1998). The TOVA provides standard scores based on unaffected individuals and also relates them to a sample of individuals with ADHD in order determine if performance is within the normal range or similar to that of individuals with ADHD (Hunt, Bienstock, & Qiang, 2012).

Similar to other CPTs, the TOVA measures errors of commission (incorrectly selecting a non-target) and omission (missing the target) to identify impulsivity and inattention, respectively. Similar to the ImPACT, the TOVA provides a measure of simple response time. Additionally, the TOVA evaluates response time variability, correct response time and response sensitivity. The variability scores measure changes in response times throughout the test, and is sensitive to the presence of ADHD. Individuals with ADHD also have slower response times, and on the TOVA have longer correct response times. Response sensitivity evaluates the deterioration in performance over time. Although most individuals demonstrate performance deterioration, individuals with ADHD typically have a quicker deterioration rate (Greenberg et al., 1994).

Commonalities Across SRC and ADHD

Many ADHD symptoms resemble the neurocognitive deficits associated with concussion (McCrory et al., 2013). As such, the overlap of symptoms between SRC and ADHD poses a potential barrier to SRC assessment. Specifically, impairments in concentration and working memory can be found in individuals with ADHD and in otherwise healthy athletes after concussion. Given that concussed athletes demonstrate neurocognitive deficits on the ImPACT, individuals with ADHD may demonstrate similar neurocognitive deficits on the ImPACT even if they have not experiences a concussion.

The ImPACT's modules resemble the aforementioned traditional neurocognitive assessment tools (the Stroop test, the WCST, the WMI and PSI, and the TOVA). For example, although the Stroop is not administered on a computer, it resembles the format of the Color Match module of the ImPACT. Furthermore, although the ImPACT modules do not exactly mirror the neurocognitive assessment tools, they test similar functions. For example, the WCST involves visual working memory and learning; the X's and O's module of the ImPACT measures working memory and visual processing speed, while Symbol Matching measures learning and memory. Therefore, individuals with ADHD would be expected to perform poorer on the portions of the ImPACT that align with these assessment tools (see Table 2).

Impact Performance for Athletes with ADHD

Few published studies exist that investigate ImPACT performance of children and adolescents with ADHD. However, two studies demonstrated that adolescents with ADHD tended to perform poorer on the ImPACT than adolescents without ADHD at baseline (Elbin et al., 2013; Zuckerman, Lee, Odom, Solomon, & Sills, 2013). Additionally, when administered the ImPACT twice within a two-week period, high school athletes with ADHD had a significantly higher likelihood of producing two invalid ImPACT profiles (i.e., Impulse Control composite) than high school athletes without ADHD (Schatz et al., 2012).

Elbin et al. (2013) used a cross-sectional design to analyze ImPACT baseline scores of United States high school and collegiate athletes tested between the years of 2009 and 2011. After excluding participants with invalid baseline profiles, four subsamples of athletes were created: athletes with a self-reported diagnosis of ADHD only (n = 882), LD only (n = 396) comorbid ADHD/LD (n = 161), and a randomly selected control group (n = 938) derived from a larger sample of 23,760. There were no statistically significant age or gender differences between the ADHD subsample (M = 15.32, SD = 1.43; 73% men, 27% women) and the control group (M = 15.35, SD = 1.43; 54% men, 46% women). The ADHD subsample produced baseline mean neurocognitive composite scores within the average range and a mean total symptom score within the normal range. An analysis of covariance (ANCOVA), co-varied for age, identified statistically significant differences on all baseline ImPACT composite scores with the exception of verbal memory. Although the ADHD group's means were within the normal range, the control group performed significantly higher on all the ImPACT composites, with the exception of verbal memory, and endorsed fewer concussion symptoms. Further, when compared with the ADHD-only group, the LD-only group performed significantly poorer on verbal memory, visual motor speed, and reaction time. The comorbid LD/ADHD group performed significantly poorer on visual motor speed and reaction time than did the ADHD-only group.

Zuckerman et al. (2013) analyzed the ImPACT baseline data of high school athletes in Tennessee that were tested between the years 2007 and 2012. They included a self-reported ADHD only subsample ($n = 262$; M age = 15.8 years), an LD only subsample ($n = 90$; M age = 16.2 years), and a comorbid ADHD/LD subsample ($n = 55$; M age = 16.0 years). A control group was created and matched on age, sex, education (in years), height, weight, Body Mass Index and number of prior concussions ($n = 407$; M age = 15.9 years). A Mann-Whitney U-test, with a significance level set at $\alpha = .05$, identified statistically significant differences between the ADHD only subsample and the control group on all six scores of the ImPACT. Analyses of the LD only, ADHD only and comorbid LD/ADHD subsamples revealed that the ADHD only subsample performed significantly better on all composites, with the exception of Visual Motor Speed.

Schatz et al. (2012) assessed the utility of repeated ImPACT baseline administrations in a sample of athletes, ages 11 to 22 years, from Pennsylvania, New Jersey, Tennessee, and Texas during the years 2009 to 2012. Individuals whose profiles were determined invalid were asked to return for retesting within two weeks of the initial baseline assessment. Of the 836 initially invalid profiles, 156 athletes (18.6%) were reassessed. Individuals with self-reported diagnoses of ADHD ($n = 9$; 5.8%), LD ($n = 6$; 3.8%), and comorbid ADHD/LD ($n = 1$; <1%) contributed to sixteen (10.3%) of the initial 156 invalid baseline profiles and seven (35%) of the 20 subsequent invalid baseline profiles. The authors conclude that the larger portion of invalid profiles from individuals with ADHD/LD "likely represents the nature of these disorders, increasing the importance of carefully and contextually evaluating test results in this group of athletes" (Schatz et al., 2012; p. 663).

Summary and Research Aims

Empirical evidence indicates that deficits exist in many individuals with ADHD on traditional neuropsychological tests that tap into domains similarly measured by the ImPACT modules; a sample of these tests includes the Stroop, WCST, WAIS-IV, WISC-IV, and TOVA. This empirical evidence, in conjunction with the previously cited data on the ImPACT performance of athletes with ADHD, provides a foundation for hypothetical ImPACT profile patterns of adolescent athletes with ADHD. Although the limitations of the ImPACT's psychometric properties and the consequential influence of systematic error must be considered, there is evidence to suggest that adolescents with ADHD will demonstrate deficits on each of the ImPACT neurocognitive modules (i.e., visual and verbal memory, visual motor speed, and reaction time) as well as overall test validity (i.e., impulse control) and reported concussion symptoms (i.e., total symptom). Therefore, deficits are expected on each of the ImPACT composite scores.

The use of normative data for post-concussion comparison of individuals with ADHD requires caution (Elbin et al., 2013), because impaired scores may actually reflect "normal" or non-concussed profiles associated with comorbid conditions such as ADHD; as a consequence, athletes with ADHD may inaccurately be given an SRC diagnosis (Moser, Fryer, Berardinelli, & Webbe, 2011). The ImPACT's test developers acknowledge the necessity of testing individuals with ADHD at baseline and advise against the use of normative data for individuals with ADHD (Lovell, 2013). Iverson et al. (2003) have shown that the greatest change post-concussion appears on the verbal memory and reaction time composite scores of the ImPACT; therefore, non-concussed athletes with ADHD, although expected to show impairment on the ImPACT, may not show impairment on the verbal memory and reaction time composite scores compared with athletes who actually experienced concussion. The need for a more in-depth understanding of the performance of high school athletes with ADHD on the ImPACT is critical for clinicians who administer and interpret the ImPACT, particularly with regards to use of normative data.

This study evaluates the ImPACT performance of athletes with ADHD by comparing four specific ImPACT neurocognitive domains, one concussion symptom score, and one validity domain between high school athletes with and without ADHD. This study focuses upon the comparison of baseline performance for athletes with and without ADHD, and the comparison of the typical (i.e., baseline) performance of athletes with ADHD with post-concussion performance of athletes without ADHD. The following hypotheses will be tested:

AIM 1: To evaluate baseline ImPACT performance of high school athletes with and without ADHD.

Hypothesis 1: Significant differences will exist at baseline between high school athletes with and without ADHD on all ImPACT composite scores including: Verbal memory, Visual memory, Reaction time, Visual motor processing speed, Impulse control, and the total score on the Symptom checklist.

AIM 2: To evaluate the ImPACT's ability to distinguish between ADHD and concussion by comparing the baseline scores of non-concussed athletes with ADHD and the post-concussion scores of concussed student athletes without ADHD.

Hypothesis 2: No significant differences will exist between non-concussed athletes with ADHD at baseline and post-concussion concussed athletes without ADHD on the following ImPACT composite scores: Visual memory, Reaction time, Visual motor processing speed, Impulse control, and the Total symptom score.

Hypothesis 3: Post-concussion performance of athletes without ADHD will be significantly lower than that of the baseline performance of non-concussed athletes with ADHD on the verbal memory composite.

CHAPTER THREE

Method

Participants

Data for this study were obtained from a larger study of SRC in high school and college athletes. The sample was recruited from a private high school in the Dallas/Fort Worth Metroplex. Inclusion criteria required participants to be student athletes involved in sports considered high risk for SRC (i.e., football, cheerleading, men's and women's basketball, men's and women's soccer, baseball, softball, and track and field). Therefore, the only exclusion criterion was denial of consent for data to be used for research purposes. Data were assessed for validity and participants also were excluded when ImPACT profiles were determined invalid. Student athletes were allowed to withdraw from the study at any time. Incentives offered to participants included an increased understanding of the effects of their injury. Thirty-eight student athletes with ADHD (M_{age} = 14.03, SD = 1.54, age range: 11-17 years) were identified for the study. A control group of thirty-eight athletes without ADHD (M_{age} = 14.03, SD = 1.62, age range: 12-17 years), matched for gender, height, weight, handedness, race and age, was created to test the first hypothesis. During the course of the study, 23 athletes sustained a concussion (M_{age} = 14.78, SD = 1.17, age range: 12-17 years) and produced valid immediate post-concussion ImPACT profiles; these 23 athletes were used to create the control group (i.e., concussed athletes without ADHD) to test the second and third hypotheses. A group of 23 athletes with ADHD (M_{age} = 14.43, SD = 1.38, age range: 12-17 years) tested at baseline were selected from the total sample of 38 students with ADHD. They were matched with the control group on gender, height, weight, handedness, race and age. The two subgroups of 46 athletes were used to test the second and third hypotheses.

During the course of the study, four participants with ADHD experienced a concussion (M_{age} = 16, SD = .82, age range: 15-17 years). The sample consisted of predominately Caucasian (100%) male (75%) athletes. Their data were examined separately, as the sample was not large enough to enter into the analysis.

Procedures

Prior to testing, informed consent was obtained from participants and their parents or legal guardians. Although testing is mandated by the school's concussion policy, participants were asked for permission to analyze their data for research purposes. Baseline testing was conducted at the University of Texas at Arlington (UTA) Brain Injury Laboratory as well as on the private school's campus (computer lab) to establish pre-injury/baseline levels of individual participants. Participants were reassessed biennially as recommended by the test manufacturer. Baseline assessment included gathering demographic information, the ImPACT, self-reported symptoms, and computerized dynamic posturography. Participants were diagnosed with SRC by a certified and licensed athletic trainer or physician. Following the diagnosis of a concussion, participants were re-administered the test battery within 48 to 72 hours after injury in the Brain Injury Laboratory. Once SRA, participants were re-administered the test battery. Participants whose test values were not considered within normal limits compared to pre-injury values were reevaluated once symptom free by self-report or approximately 48 hours following the most recent assessment. Electronic data were stored on an encrypted computer in a secure laboratory and paper questionnaires were stored in a locked file cabinet in a secure office on the UTA campus.

Measures

The Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) is a computerized test and takes approximately 25 minutes to complete. The ImPACT includes three components: demographics, neurocognitive test battery, and ratings of post-concussion symptoms (PCSS). The demographic information obtained includes relevant sport, medical, and concussion history. The neurocognitive test battery of the ImPACT provides five composite scores upon completion: verbal memory, visual memory, reaction time, visual motor processing speed, and impulse control.

Reliability. Test-retest reliability coefficients estimate the stability of test point scores across time. Stability across testing points is particularly relevant to neurocognitive assessment; interpretation of changes between baseline and post-injury scores on the ImPACT are, theoretically, generally reflective of the neurocognitive effects of concussion rather than various sources of potential error. Test-retest reliability coefficients are calculated using various statistical procedures and ranges from 0 to 1 (Webb, Shavelson, & Haertel, 2006).

The ImPACT demonstrates variable test-retest reliability with respect to testing intervals and composite scores. Using an extended interval design, the ImPACT demonstrated moderate to strong (.46 to .85) test-retest reliability when the test points were spaced one to three years apart (Elbin et al., 2011; Schatz, 2009). Both Elbin et al. (2011) and Schatz (2009) found the greatest stability in processing speed and lowest stability in verbal memory. However, four studies demonstrated that test-retest reliability ranges between .23 and .88 in designs that more accurately match the concussion management return-to-play testing design (Register-Mihalik et al., 2012; Schatz and Ferris, 2013; Broglio et al., 2007a; Resch et al., 2013a). Specifically, they found the weakest reliability coefficients on verbal and visual memory and the strongest reliability coefficients on visual motor speed, processing speed and reaction time.

Validity. Test validity refers to the extent to which a test measures what it intends to measure. Three studies demonstrated the ImPACT's variable concurrent validity, ranging from .20 to .88 (Allen & Gfeller, 2011; Maerlender et al., 2010; Resch et al., 2013b). Notably, the ImPACT demonstrated statistically significant concurrent validity with the Symbol Search, Coding and Digit Span subtests of the WAIS-III (Allen & Gfeller, 2011; Schatz & Putz, 2006).

To date, four studies assessed the ImPACT's sensitivity and specificity. Across these studies, the ImPACT demonstrated sensitivity ranging from 79.2% to 94.6% and specificity ranging from 69.1% to 97.3% (Broglio et al., 2007b; Schatz, Pardini, Lovell, Collins, & Podell, 2006; Schatz & Sandel, 2013; Van Kampen, Lovell, Pardini, Collins, & Fu, 2006).

CHAPTER FOUR

Results

For Hypothesis 1, the sample (N = 76) consisted of thirty-eight athletes with ADHD and a control group of thirty-eight athletes without ADHD. Analyses were conducted to determine if the two groups differed by self-reported race, sport played, and age. Chi-square analyses revealed no significant differences between the athletes with ADHD and without ADHD for race (χ^2 = .02, p = .89) or sport played (χ^2 = 20.09, p = .52). An independent t-test showed no significant difference in mean age for the two groups (t(73 = .002, p = .74). Table 3 shows demographic information for the sample used to test Hypothesis 1.

For Hypotheses 2 and 3, the sample (N = 46) consisted of twenty-three concussed athletes without ADHD and twenty-three athletes with ADHD tested at baseline. Analyses were conducted to determine if the two groups differed by self-reported race, sport played, and age. Chi-square analyses revealed no significant difference between the athletes with ADHD and immediately tested, concussed athletes without ADHD for race (χ^2 = 1.44, p = .70) or sport played (χ^2 = 10.13, p = .26). An independent t-test showed no significant difference in mean age for the two groups (t(27) = .-.98, p = .34). Table 4 shows the demographic information for the sample used to test Hypotheses 2 and 3.

Descriptive Statistics

Tables 5 and 6 provide descriptive statistics (means, standard deviations, and percentiles) for the ImPACT scores in both the ADHD and non-ADHD groups tested. Higher scores on verbal memory, visual memory and visual motor speed composite scores indicate better performance, whereas lower scores on reaction time and impulse control indicate better performance; high symptom scores indicate a greater symptom severity.

For the overall sample (n=76), the mean baseline neurocognitive composite scores and the symptom score were within the average range. The mean neurocognitive composite scores and symptom score for both the ADHD and healthy control groups were within the average range. At immediate post-concussion testing, the mean neurocognitive composite scores for the overall sample (n=46) were within the average range. The mean neurocognitive composite scores for the ADHD and healthy control groups were within the average range. While the ADHD subsample total symptom score (57^{th} percentile) was within the average range, the non-ADHD subsample total symptom score (82^{nd} percentile) was above average.

Results of Hypothesis-Testing

Hypothesis 1. Significant differences will exist at baseline between high school athletes with and without ADHD on all neurocognitive composites of the ImPACT and the total symptom score.

Independent samples *t*-tests revealed significant differences between athletes with ADHD and non-ADHD athletes at baseline on the Impulse Control ($t_{(74)} = 2.73$, $p < .01$) and the Total Symptoms ($t_{(74)} = 2.63$, $p < .05$) scores of the ImPACT. No significant between-group differences were observed on the Verbal Memory, Visual Memory, Visual Motor Speed or Reaction Time scores. Therefore, Hypothesis 1 was partially supported, as differences were detected between athletes with and without ADHD on two of the six baseline scores (see Table 5).

Hypothesis 2. No significant differences will exist between non-concussed athletes with ADHD at baseline and post-concussion concussed athletes without ADHD on the following ImPACT composites: visual memory composite, reaction time composite, visual motor processing speed composite, impulse control composite.

Hypothesis 3. Post-concussion performance of athletes without ADHD will be significantly lower than that of the baseline performance of non-concussed athletes with ADHD on the verbal memory composite.

A multivariate analysis of variance (MANOVA) was conducted on data from two testing data points. There was a statistically significant difference ($F(6, 39) = 2.86$, $p = .02$; Wilks' $\Lambda = 0.694$; $\eta^2 = .31$) in ImPACT performance between non-concussed athletes with ADHD tested at baseline and concussed athletes without ADHD tested within 72 hours of injury (M = 1.83 days). Further analysis using independent samples *t*-tests found that athletes with ADHD at baseline performed significantly better than concussed athletes without ADHD tested within 72 hours of injury, on the following composites: Verbal Memory ($t_{(44)} = 2.25$, $p = .03$), Visual Motor Speed ($t_{(44)} = 2.33$, $p = .02$), Reaction Time ($t_{(44)} = -3.42$, $p = .001$), and Total Symptom ($t_{(44)} = -3.52$, $p = .001$). No significant between-group differences were found on the Visual Memory ($t_{(44)} = 1.53$, $p = .13$) or Impulse Control ($t_{(44)} = .61$, $p = .54$) composites of the ImPACT. Thus, Hypothesis 2 was partially supported by two of the five comparisons of ImPACT composites scores (see Table 6). Hypothesis 3 was fully supported, as the performance of concussed athletes without ADHD was significantly lower than the baseline performance of non-concussed athletes with ADHD for the verbal memory composite (see Table 6).

ADHD Concussion Cases

Over the course of the study, four individuals with ADHD sustained a concussion. The sample size was not large enough to compare ImPACT mean scores' of concussed individuals with and with ADHD. However, descriptive analyses were conducted to explore the post-concussion ImPACT performance of individuals with ADHD. Since the results below reflect data from a limited sample size (n = 4) and may not accurately represent all post-concussion profiles of individuals with ADHD, interpretations should be made with caution.

Baseline and post-concussion data were examined for the four participants with ADHD who experienced a concussion. At baseline, the age range was 14 to 16 years (M = 14.75; SD = .96) and at injury the age range was 15 to 17 years (M = 16; SD = .82). Table 7 shows additional demographic information.

Descriptive Statistics. Table 8 provides descriptive statistics (means, standard deviations and percentiles) for the ImPACT mean baseline and immediate post-concussion composite scores and symptom scores of the four individuals with ADHD who sustained a concussion. For the four individuals with ADHD who sustained a concussion, the mean neurocognitive baseline composite scores and the symptom score were all within the average range. The mean neurocognitive immediate post-concussion composite scores were variable; while verbal memory, visual memory and visual motor speed were within the average range, reaction time was below average. The mean total symptom immediate post-concussion composite was above average.

CHAPTER FIVE

Discussion

This study evaluated the ImPACT's accuracy in distinguishing baseline profiles of high school athletes with and without ADHD. Additionally, this study evaluated the ImPACT's ability to distinguish between ADHD and concussion by comparing the ImPACT profiles of athletes with ADHD tested at baseline with the post-concussion profiles of athletes without ADHD. The results indicate that, while some of the hypothesized differences were partially supported, others were not supported.

Hypothesis 1

Contrary to expectations, no differences on ImPACT baseline composite scores between ADHD and non-ADHD student athletes were observed on verbal memory, visual memory, visual motor speed, and reaction time. In this sample, there is likely little influence of ADHD symptoms on ImPACT baseline performance on tasks of verbal and visual attention, learning and memory, visual scanning, visual-motor response speed and overall response speed. As expected, athletes with ADHD obtained higher impulse control and total symptom scores; athletes with ADHD at baseline made more errors and reported more symptoms associated with concussion than did the athletes without ADHD tested at baseline. Despite the statistically significant difference, both the ADHD group and the healthy control group produced valid impulse control scores (i.e., < 30). Therefore, the difficulties with behavioral inhibition and impulsivity in individuals with ADHD likely contributed to the significantly higher impulse control composite, but did not invalidate the test. Because the impulse control composite is used as one of the ImPACT validity indicators, individuals with ADHD tested at baseline may produce a higher impulse control score but for reasons other than carelessness, confusion, fatigue, "horseplay," or sandbagging. Similar to the performance problems seen on other computerized tests of attention and impulsivity (e.g., TOVA), performance in this cognitive domain may simply be characteristic of individuals with ADHD.

These findings differ from the findings of two previous studies of ImPACT baseline performance for athletes with ADHD. Elbin et al. (2013) found that adolescents with ADHD differed from controls on four ImPACT composite scores as well as the total symptom score, although the two groups did not differ on verbal memory and impulse control scores. Is should be noted that the verbal memory composite has the lowest reliability data for the ImPACT, reducing the clarity of this finding. Zuckerman et al. (2013) found that the two groups differed on all five ImPACT composite scores as well as the total symptom score. However, it appears that baseline testing in these two studies was conducted in a group setting versus the individualized administration in the current study. As evidence suggests that baseline scores of participants tested in a group setting are poorer than baseline scores of participants tested individually, this factor may account for their lower scores (Moser, Schatz, Neidzwski, & Ott, 2011).

Notably, both the control and the ADHD groups in each of these studies obtained means that were, generally, within the average range but a significant group difference was found nonetheless. The current study's smaller sample size may account for the lack of significance. Inspection of the test scores reveals a trend for scores of the athletes with ADHD to be consistently worse than those of the non-ADHD group. Therefore, an increased sample size and corresponding increased power may have been able to detect true differences. Clearly, additional studies of athletes with ADHD need to be conducted. Given the limited number of studies, and the absence of differences on any of the four ImPACT neurocognitive domains in the current study, these results support the interpretation of baseline profiles of individuals with ADHD and the use of normative data for the ADHD population.

However, as individuals with ADHD produced significantly higher baseline impulse control and symptom severity scores, it is likely that these portions of the ImPACT are particularly sensitive to the presence of ADHD. Potential adjustments to the use of ImPACT with this population may be warranted. These may include revision of the Post-Concussion Symptom Scale instructions (e.g., "rate your current experience of each symptom beyond that which is related to ADHD symptoms") or other special modifications (e.g., separate impulse control cut-off scores for individuals with ADHD).

Hypotheses 2 and 3

Contrary to expectations, concussed athletes without ADHD performed worse than uninjured athletes with ADHD on three of the four ImPACT neurocognitive composites. Additionally, concussed athletes without ADHD endorsed greater concussion symptom severity. Generally speaking, athletes without ADHD do show cognitive impairment after a concussion that is beyond the level of impairment associated with ADHD. Moreover, concussed athletes without ADHD report greater concussion symptom severity than do athletes with ADHD at baseline. The ImPACT appears able to differentiate between individuals with and without concussion, despite the presence of ADHD, on tasks of verbal memory, visual-motor response speed and overall response speed, as well as on the self-reported concussion symptom severity.

As expected, the performance of uninjured athletes with ADHD is indistinguishable from that of concussed athletes on tasks of visual memory and impulse control. Therefore, the ImPACT is unlikely to differentiate ADHD from concussion through evaluation of errors committed or on the visual memory tasks. The impulsivity associated with ADHD is likely to account for the similarities in mean impulse control composite scores for ADHD and athletes after concussion. As indicated by Iverson et al. (2003), verbal memory may be more reactive to the effects of concussion than visual memory. Therefore, as expected, the visual memory composite for the concussed athletes did not fall below the level displayed by the uninjured athletes with ADHD, whereas a difference was found for the verbal memory composite. Similarly, visual-motor speed and reaction time were affected by concussion beyond any characteristics typical of individuals with ADHD. Further research into ImPACT modules may shed light onto these differences.

Overall, having ADHD does not mimic the neurocognitive effects associated with concussion. For the most part, concussion does produce ImPACT neurocognitive scores that are worse than those produced by ADHD. However, given that athletes with ADHD at baseline and athletes without ADHD at immediate post-concussion performed similarly on measures of visual memory and impulse control, these portions of the ImPACT profiles of individuals with ADHD should be interpreted with caution. Further, increased clinician awareness of ADHD relevance in concussion management with respect to impulse control and total symptom scores on the ImPACT may be beneficial. These findings suggest a need for additional ImPACT research into ADHD performance on the ImPACT before and after concussion.

ADHD Concussion Cases

As the sample size of the four individuals with ADHD who sustained concussion was too small for statistical analyses, descriptive analyses were conducted and trends over time were assessed. The findings suggest that, while the group’s neurocognitive performance and symptom score were within the average range at baseline, neurocognitive performance appeared to decline following concussion. The total symptom score increased dramatically, as the mean score went from the average range (31^{st} percentile) at baseline, to above average (87^{th} percentile) post-concussion. This trend suggests that, despite the overlap in symptoms, individuals with ADHD may follow the same general post-concussion pattern on the ImPACT.

Limitations and Future Research

A number of limitations to the current study merit discussion. The sample in this study was restricted in size and age range. Future research should strive to recruit a larger sample of participants with ADHD with a greater age range to increase generalizability. Notably, a large portion of our sample did not report ethnicity. This poses a limitation to the interpretation of the post-concussion findings in particular, as previous research has documented statistically significant differences between African-American and Caucasian post-concussion ImPACT profiles (Kontos, Elbin, Covassin & Larson, 2010). Additionally, the control group used to test Hypothesis 1 did not include the same participants used to test Hypotheses 2 and 3. Therefore, conclusions cannot be drawn regarding the observed changes from baseline to post-concussion in the ImPACT performance of individuals without ADHD. Confirmation of an ADHD diagnosis was not used as an inclusion criterion in this study. Therefore, relevant and comprehensive information, such as identification of ADHD subtype and symptom severity, was not collected and differences between inattentive and hyperactive subtypes, for example, may have gone undetected. Additionally, medication use was not evaluated in the present study. Specific information about ADHD medication type, dosage, and most recent use may prove informative. Individuals who used medication on the day of testing may not accurately represent the cognitive deficits seen in ADHD and may perform better than those who are not prescribed medication or who did not take prescription medication prior to testing. Future research should consider either consultation to obtain collateral diagnostic and medication information or inclusion of a comprehensive diagnostic evaluation in the methodology. Finally, concerns regarding the ImPACT's reportedly variable reliability pose limitations to the interpretation of ImPACT data (Broglio et al., 2007a; Elbin et al., 2011; Register-Mihalik et al., 2012; Resch et al., 2013a; Schatz and Ferris, 2013; Schatz, 2009).

This study compared the baseline and post-concussion ImPACT profiles of individuals with and without ADHD in order to contribute to the research on computerized neurocognitive concussion assessment in individuals with ADHD. At this time, administration of the ImPACT to individuals with ADHD is appropriate. However, certain areas of overlap in ADHD and concussion profiles warrant caution in the clinical interpretation of the ImPACT profiles of individuals with ADHD. Nevertheless, these findings suggest that the use of baseline testing and normative data for an ADHD population is appropriate.

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Table 1

Descriptions of ImPACT Modules and Composite Scores

Module	Domains
Word Discrimination	Verbal recognition memory
Design Memory	Visual memory
X's and O's	Visual working memory and visual processing speed
Symbol Matching	Visual processing speed, learning and memory
Color Match	Reaction time, impulse control and response inhibition
Three Letters	Verbal working memory and visual-motor response speed

Composite Score	Module(s)
Verbal Memory	Total memory percent correct; symbol match (total correct hidden symbols); three letters (total percent of total letters correct)
Visual Memory	X's and O's (total correct memory score); design memory (total percent correct score)
Processing Speed	X's and O's (total correct (interference)); three-letters (average counted correctly)
Reaction Time	X's and O's (average correct RT (interference)); symbol match (average correct RT/3); color match (average correct RT)
Impulse Control	X's and O's (total incorrect (interference)); color match (total commissions)
Total Symptom	Sum of endorsed symptoms

Table 2

Commonalities Across Traditional Neuropsychological Tests and ImPACT

ADHD Related Tests	ImPACT Modules
Stroop	Color Match
WCST	X's and O's Symbol Matching
Working Memory Index*	Design Memory X's and O's Symbol Matching
Processing Speed Index*	Design Memory X's and O's Symbol Matching
TOVA	Commission scores: • X's and O's • Color Match Average correct response times: • X's and O's • Symbol Match • Color Match

*WAIS-IV and WISC-IV

Table 3

Demographic Data for ADHD and Controls at Baseline; N=76

Variable	**ADHD**		**Control**	
Gender				
Male	28	73.7%	28	73.7%
Female	10	26.3%	10	26.3%
Race				
Caucasian	13	34.2%	30	78.9%
African American	2	5.3%	3	7.9%
Hispanic	0	0.0%	2	5.3%
Asian or Pacific Islander	0	0.0%	3	7.9%
Missing	23	60.5%	0	0.0%
Handedness				
Right	27	71.1%	27	71.1%
Left	9	23.7%	8	21.1%
Ambidextrous	2	5.3%	2	5.3%
Missing	0	0.0%	1	2.6%
Current Sport				
Football	15	39.5%	15	39.5%
Track and Field	5	13.2%	7	18.4%
Baseball	1	2.6%	3	7.9%
Basketball	2	5.3%	3	7.9%
Golf	0	0.0%	1	2.6%
Volleyball	2	5.3%	6	15.8%
Soccer	2	5.3%	2	5.3%
Tennis	1	2.6%	0	0.0%
Swimming	2	5.3%	0	0.0%
Cheer	0	0.0%	1	2.6%
Rodeo	1	2.6%	0	0.0%
Ice Hockey	1	2.6%	0	0.0%
Missing	6	15.8%	0	0.0%

Table 4

Demographic Data for Immediate Post-Concussion Comparisons; N=46

Variable	**ADHD**		**Control**	
Gender				
Male	19	82.6%	19	82.6%
Female	4	17.4%	4	17.4%
Race				
Caucasian	10	43.5%	20	87.0%
Hispanic	0	0.0%	1	4.3%
American Indian or Alaskan Native	0	0.0%	1	4.3%
Native American	0	0.0%	1	4.3%
Missing	13	56.5%	0	0.0%
Handedness				
Right	18	78.3%	19	82.6%
Left	3	13.0%	3	13%
Ambidextrous	2	8.7%	1	4.3%
Current Sport				
Football	10	43.5%	12	52.2%
Track and Field	1	4.3%	6	26.1%
Baseball	1	4.3%	2	8.7%
Basketball	1	4.3%	0	0.0%
Volleyball	2	8.7%	3	13.0%
Soccer	1	4.3%	0	0.0%
Swimming	2	8.7%	0	0.0%
Rodeo	1	4.3%	0	0.0%
Ice Hockey	1	4.3%	0	0.0%
Missing	3	13.0%	0	0.0%

Table 5

Means (SDs) and Percentiles for ImPACT Scores at Baseline, by Group

Variable	ADHD n = 38			Non-ADHD n = 38			*t* value	*p* value
Verbal Memory	80.3	(9.84)	43rd	84.00	(9.06)	52nd	-1.67	.10
Visual Memory	70.11	(14.19)	43rd	75.42	(12.30)	55th	-1.75	.09
Visual Motor Speed	33.33	(8.34)	38th	36.04	(6.86)	49th	-1.51	.13
Reaction Time	.63	(.11)	46th	.59	(.09)	60th	1.51	.14
Impulse Control	9.39	(4.66)	-	6.71	(3.88)	-	2.73	.01
Total Symptom	8.53	(11.55)	57th	3.18	(4.85)	53rd	2.63	.01

Table 6

Means (SDs) and Percentiles for ImPACT Scores, Immediate Post-Concussion, by Group

Variable	ADHD n = 23			Non-ADHD n = 23			*t* value	*p* value
Verbal Memory	81.43	(9.16)	45th	72.57	(16.58)	32nd	2.25	.03
Visual Memory	72.17	(15.58)	47th	65.30	(14.88)	34th	1.53	.13
Visual Motor Speed	35.67	(7.40)	46th	30.26	(8.30)	27th	2.33	.02
Reaction Time	.60	(.07)	52nd	.75	(.20)	29th	-3.42	.00
Impulse Control	9.17	(4.67)	-	8.30	(4.95)	-	.61	.54
Total Symptom	7.39	(8.86)	57th	20.22	(15.07)	82nd	-3.52	.00

Table 7

Demographic Data for Athletes with ADHD; N = 4

Variable	**N**	**%**
Gender		
Male	3	75.00%
Female	1	25.00%
Race		
White	4	100%
Handedness		
Right	3	75.00%
Left	1	25.00%
Current Sport		
Football	1	25%
Track and Field	1	25%
Golf	1	25%
Volleyball	1	25%

Table 8

ImPACT Means (SDs) and Percentiles for ImPACT scores of Athletes with ADHD

Variable	Baseline 1 n = 4			Post-Injury n = 4		
Verbal Memory	81.25	(17.42)	49th	75.00	(19.30)	35th
Visual Memory	74.00	(14.33)	49th	66.75	(21.41)	39th
Visual Motor Speed	38.57	(3.18)	58th	36.16	(6.29)	37th
Reaction Time	.64	(.04)	30th	.67	(.06)	21st
Impulse Control	6.25	(3.30)	-	8.25	(10.72)	-
Total Symptom	2.00	(2.83)	31st	19.50	(7.19)	87th

BIOGRAPHICAL SKETCH

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Positions and Employment

2015 Research Study Coordinator for the Neuropsychometric Research Lab, Center for Brain Health

Clinical Experience

2015 Jewish Family Services
2014 - 2015 Psychology Service at Parkland
2014-2015 University Rehabilitation Services

Presentations and Publications

2015 Poster presentation at National Academy of Neuropsychology
2013 Poster presentation at Society of Behavioral Medicine
2012 Poster presentation at Association for Psychological Science
2011 Paper presentations at University of North Texas Scholar's Day
2011 Poster presentation at American Psychosomatic Society

Professional Memberships

2015 Society of Counseling Psychology, Division 17, American Psychological Association