PREDICTING CLINICAL CONCUSSION MEASURES AT BASELINE AND RE-TEST BASED ON ACADEMIC PROFILE AND MOTIVATION

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ABSTRACT

KATRINA JAVIER TRINIDAD: Predicting Clinical Concussion Measures at Baseline and Re-Test Based on Academic Profile and Motivation
(under the direction of Kevin Guskiewicz)

Purpose: To determine if motivation, unweighted high school grade point average (hsGPA), and Scholastic Assessment Test (SAT) score can predict neurocognitive and postural control performance at baseline and re-test. **Participants:** 165 incoming student-athletes. **Methods:** Participants completed a computerized neurocognitive test, a balance test, and a measure of test-taking motivation at baseline and re-test. **Statistical Analyses:** Twenty-four separate multivariate regression models were used with SAT, hsGPA, and motivation as predictors for baseline and re-test neurocognitive and postural control performance. **Results:** The model explained a small amount of the variance for the baseline psychomotor speed and complex attention domains and postural control outcomes. **Conclusion:** Baseline motivation index, SAT and hsGPA do not predict a majority of the clinical concussion measures at baseline and/or re-test but should be considered when assessing the validity of baseline scores.

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LIST OF ABBREVIATIONS

BESS –Balance Error Scoring System

CDC – Center for Disease Control

ES – Composite Equilibrium Score

DCT – Rey's Dot Counting Test

hsGPA – High school grade point average

NATA – National Athletic Trainers' Association

NCT – Neurocognitive test

SAC – Standard Assessment of Concussion

SAT – Scholastic Assessment Test

SOT – Sensory Organization Test

TBI – Traumatic brain injury

CHAPTER 1

INTRODUCTION

Introduction

The National Collegiate Athletic Association's (NCAA) injury surveillance system reports that traumatic brain injuries (TBIs) have affected over 9,000 student athletes in only 16 years (Hootman, Dick et al. 2007). This has caused the belief that concussions and brain injuries are "a part of the game" by many individuals in the athletic community. It has taken medical professionals years to rid the athletic community of the term 'ding' as it demeans the severity of the injury. In 2004, the International Classification of Diseases reclassified concussion as a traumatic brain injury (TBI), however, many non-medical personnel still do not understand the severity (Centers for Disease Control and Prevention (U.S.) and Centers for Medicare & Medicaid Services (U.S.) 2004). The broad term TBI includes different grades of injury, from mild, moderate and severe. Concussion, a form of mild traumatic brain injury, is the most common type of TBI in sport. The exposure of sport-related concussion in the media has increased with a number of popular professional athletes sustaining concussions. Recently, both the National Athletic Trainers' Association (NATA) and the Centers on Disease Control have made efforts to improve the education of concussion signs and symptoms for athletes, coaches, athletic trainers, and parents. The NATA's position statement asserts that all sports medicine professionals use a multi-faceted approach including a thorough clinical evaluation, that includes measures of neurocognition, postural control, and symptom severity to assess athletes following concussion (Guskiewicz, Bruce et al. 2006)

Neurocognitive testing (NCT) has been used in the sports medicine setting for a number of years to aid in the management of sport-related concussions. With the advent of computerized technology, computerized NCT testing is becoming more commonplace in sports medicine clinical setting to assess baseline and post-concussion neurocognitive status. Athletic programs across the country have utilized this technology at all levels (Notebaert and Guskiewicz 2005). Researchers and manufacturers recommend that baseline NCTs be used in many athletic programs to assess neurocognitive performance prior to a season of play and again if the athlete were to sustain a concussion (McCrory, Meeuwisse et al. 2009). The purpose of baseline testing is to aid the medical staff in understanding the amount of change that has occurred due to the injury to guide return to play decisions.

Postural control assessment is also an integral part of a post-concussion evaluation (Riemann and Guskiewicz 2000; Guskiewicz, Ross et al. 2001; McCrory, Meeuwisse et al. 2009). Postural control can be best described as the body's ability to maintain one's center of gravity over the base of support (Horak 1987). In a study of concussed athletes, from the high school to professional level, almost 50% reported symptoms of "balance problems" post injury (Lovell, Iverson et al. 2006). These postural stability or balance deficits have been found to be clinically significant from baseline to day 1 post injury and on average did not resolve until day 3 post injury in a collegiate student-athlete population (Guskiewicz, Ross et al. 2001).

The symptoms of concussions are different depending on the individual as concussions affect a variety of sensory systems including and not limited to neurocognition and postural control. Part of the clinical assessment of sport-related concussion is a graded symptom checklist, which asks the injured athlete about the severity of their symptoms. The most common symptoms, which include headache and neck pain occur in over half of all concussions seen in the NFL (Pellman, Powell, et Al, 2004). The graded symptom checklist is a very important tool in understanding what the extent and the severity of the TBI and can often times help medical personnel in identifying the type of TBI.

Recently, the NCAA mandated that all member institutions must have a concussion policy on file and require that athletes of all sports are made aware of the possibilities of sport-related concussions (Brasfield 2010). Upon recommendation by the research community, many institutions now incorporate the use of serial clinical concussion measures in the post-injury evaluation. Fearful of a change in their participation status, many athletes may intentionally do poorly during baseline testing in order to return to play sooner. However the poor performance at baseline may not wholly be due to the possibility of return to play sooner, rather it may be due to pure disinterest in the tests. This leaves many sports medicine professionals with the problem of invalid baseline scores that may not provide a true representation of the athlete's capabilities. Invalid baseline scores that go unrecognized could cause sports medicine professionals to make premature decision to allow the athlete to return to play before they have recovered from their concussion (Covassin, Elbin Iii et al. 2009). Athletes that return to play prematurely are at risk of sustaining a second, seemingly innocuous, impact that could result in death or permanent brain damage (Cantu 1998). While age-related norms can be used for individuals who have invalid baseline tests, they may not take into account subtle changes or deficits in cognition from baseline to post-injury. Many researchers suggest that serial administration of clinical concussion measures is the best way to assess athletes and make informed return to play decisions (Guskiewicz, Bruce et al.

2004).

Neurocognitive Tests are a cross-sectional measure of neurocognitive functioning in a variety of cognitive domains. Although NCT is not a diagnostic tool, serial NCTs are designed to detect changes or impairments in neurocognitive functioning over a number of days, which may be indicative of a sport-related concussion. Currently, in the sports medicine setting, preseason baseline computerized NCT performance is completed prior to or near the beginning of an athlete's freshman year. These scores become a standard that must be met for an individual to be allowed to return to play. For many individuals, the baseline is the first time they undergo NCT and are very new to this type of testing. Controversy exists regarding whether baseline NCT truly reflects an athlete's neurocognitive capabilities or their testing proficiency (Miller, Adamson et al. 2007; Randolph 2011). Reading level has been proven to affect NCT performance, but there has been no investigation of the effects of other measures of intelligence or academic ability on NCT performance in healthy or injured individuals (Manly, Jacobs et al. 2002).

Academic profile has been previously shown to have a relationship with cognitive ability (Rohde and Thompson 2007). Academic profile consists of an athlete's total Scholastic Assessment Test (SAT) and high school grade point average (hsGPA). High school GPA represents the student-athlete's cognitive performance throughout all four years of high school. The SAT is a widely accepted test used for collegiate admittance. The SAT is a cross-sectional measure that is meant to measure a student's potential for scholastic ability at the collegiate level. Similarly, the baseline NCT is also a cross-sectional measure. Evidence suggests that there is an inconsistent relationship between SAT scores and neurocognitive testing scores at baseline (Echemendia, Putukian et al. 2001; Brown, Guskiewicz et al. 2007; Miller, Adamson et al. 2007). However, due to a change in the SAT testing format, the correlations found do not reflect the new scoring and test now used by The College Board for the current population of student-athletes. Academically successful individuals have been found to be more successful because they are better test takers, in the education community this is called test-wiseness (Thorndike 1951; Sarnacki 1979). This was observed in a study conducted by Miller et al., where an interaction effect was observed between SAT score and collegiate GPA on the test-re-test reliability of a NCT (Miller, Adamson et al. 2007). It has been shown that test-wiseness is a quality that can be taught in the classroom and can improve achievement test scores (Whalstrom and Boersma 1968). Athletes that are more test-wise may have the ability to inflate their NCT performance at re-test, making them appear to be recovered from a concussive incident, when in fact they still have lingering cognitive deficits. The same theory can hold true for postural control performance, as the athlete may be able to devise test strategies to improve balance performance. Sports medicine professionals have been advised by researchers that an improved test performance, also known as a practice effect, should be expected with serial administration of NCTs and postural control measures (Echemendia, Putukian et al. 2001; Finnoff, Peterson et al. 2009). However, the extent and amount of improvement has yet to be determined. Considering recent recommendation for serial assessment during the recovery process of a sport-related concussion, it is important to understand how test-wiseness affects the results of each test session (Guskiewicz, Bruce et al. 2004; McCrory, Meeuwisse et al. 2009).

It has been established by a number of educational researchers, that academic performance is related to motivation in conjunction with cognitive ability and test-wiseness

(Terman and Oden 1959; Feldhusen 1986; Haensly, Reynolds et al. 1986). Motivation during NCTs in the sports medicine setting has only been studied by a small number of researchers, and its contribution to NCT performance is not wholly understood in the collegiate setting (Hunt, Ferrara et al. 2007). Furthermore, there has been no investigation of the effects of motivation in conjunction with academic profile information on NCT performance in both educational or sports medicine literature.

The purpose of this study is to determine if motivation index scores, SAT scores and hsGPA can predict clinical concussion measures at baseline. The secondary purpose of this study is to determine if changes in motivation index scores, SAT scores and hsGPA can predict practice effects observed between the baseline and the re-test session. The tertiary purpose of this study is to understand the relationship between average motivation across test sessions and baseline to re-test change scores for each of the cognitive domains and postural control performance.

Variables

Baseline Performance

Predictor Variables

I. Academic Profile
    a. Scholastic Assessment Test (SAT) Total Score
    b. Unweighted High School Grade Point Average (hsGPA)

II. Motivation
    a. Baseline Motivation Index Score (Research Question 1)

Criterion Variables

I. Neurocognitive Performance on the CNS Vital Signs Test Battery (CNS-VS) based on the standard scores for the following domains:

a. verbal memory
b. visual memory
c. psychomotor speed
d. reaction time
e. complex attention
f. cognitive flexibility
g. processing speed
h. executive functioning
i. reasoning

II. Sensory Organization Test (SOT)

a. Composite Score
b. Trial equilibrium change scores (trial 3 – trial 1) for condition 3
c. Trial equilibrium change scores (trial 3 – trial 1) for condition 4
d. Trial equilibrium change scores (trial 3 – trial 1) for condition 5
e. Trial equilibrium change scores (trial 3 – trial 1) for condition 6

Re-test Performance

Predictor Variables

I. Academic Profile

a. Scholastic Assessment Test (SAT) Total Score
b. Unweighted High School Grade Point Average (hsGPA)

II. Motivation

a. Average Motivation Index Score (Research Question 2 & 3)

Criterion Variables

I. Neurocognitive Practice Effect on the CNS Vital Signs Test Battery (CNS-VS) based on the change of the standard scores of the following domains:

a. verbal memory
b. visual memory

c. psychomotor speed
d. reaction time
e. complex attention
f. cognitive flexibility
g. processing speed
h. executive functioning
i. reasoning

II. Sensory Organization Test (SOT) Practice Effect

a. Composite Score Change Score

Research Questions

I. Baseline Performance

RQ1-A: Does baseline motivation index score, hsGPA, and total SAT score predict neurocognitive performance at baseline in a healthy student-athlete sample as measured by CNS-VS?

RQ1-B: Does baseline motivation index score, hsGPA and total SAT score predict postural control performance at baseline in a healthy student-athlete sample as measured by the Sensory Organization Test?

RQ1-C: Does baseline motivation index score, hsGPA and total SAT score predict acute postural control practice effects between trials one and three for conditions three through six as measured by the SOT in a healthy student-athlete sample?

II. Practice Effect Between Baseline and Re-Test Sessions

RQ2-A: Does average motivation index, hsGPA and total SAT score predict neurocognitive change scores between baseline and re-test in a healthy student-athlete sample as measured by CNS-VS?

RQ2-B: Does average motivation index, hsGPA and total SAT score predict postural control change scores between baseline and re-test in a healthy student-athlete sample as measured by the Sensory Organization Test?

III. Relationship between Motivation and Change Scores

RQ3-A: Is there a significant relationship between average motivation and neurocognitive change scores in a healthy student-athlete sample as measured by CNS-VS?

RQ3-B: Is there a significant relationship between average motivation and a postural control change score in a healthy student-athlete sample as measured by the Sensory Organization Test?

Hypotheses

Research Hypotheses

I. Baseline Performance

RH1-A: Baseline motivation index score, hsGPA, and total SAT score will predict neurocognitive performance for all domains at baseline in a healthy student-athlete sample as measured by CNS-VS.

RH1-B: Baseline motivation index score, hsGPA and total SAT score will predict postural control performance at baseline in a healthy student-athlete sample as measured by the SOT.

RH1-C: Baseline motivation index score, hsGPA and total SAT score will predict acute postural control practice effects between trials one and three on conditions three through six of the SOT in a healthy student-athlete sample.

II. Practice Effect Between Baseline and Re-Test Sessions

RH2-A: Average motivation index, hsGPA and total SAT score will predict neurocognitive change scores between baseline and re-test in a healthy student-athlete sample as measured by CNS-VS for the following domains:

a. verbal memory
b. visual memory
c. complex attention
d. cognitive flexibility
e. executive functioning
f. reasoning

And not for the following domains:

a. psychomotor speed
b. reaction time
c. processing speed

RH2-B: Average motivation index, hsGPA and total SAT score will predict postural control change scores between baseline and re-test in a healthy student-athlete sample as measured by the SOT.

III. Relationship between Motivation and Change Scores

RH3-A: There will be a negative linear relationship between average motivation and neurocognitive change score between baseline and re-test in a healthy student-athlete sample as measured by CNS Vital Signs.

RH3-B: There will be a negative linear relationship between average motivation and postural control change score between baseline and re-test in a healthy student-athlete sample as measured by the SOT.

Statistical Hypotheses

Null Hypotheses

I. Baseline Performance

$H_0$1-A: Baseline motivation index score, hsGPA, and total SAT score do not predict neurocognitive performance at baseline in a healthy student-athlete sample as measured by CNS-VS.

$H_0$1-B: Baseline motivation index score, hsGPA and total SAT score do not predict postural control performance at baseline in a healthy student-athlete sample as measured by the SOT.

$H_0$1-C: Baseline motivation index score, hsGPA and total SAT score do not predict acute postural control practice effects between trials one and three on conditions three through six of the SOT in a healthy student-athlete sample.

II. Practice effect Between Baseline and Re-Test Sessions

$H_0$2-A: Average motivation index, hsGPA and total SAT score do not predict neurocognitive change scores for all domains between baseline and re-test in a healthy student-athlete sample as measured by CNS-VS.

$H_0$2-B: Average motivation index, hsGPA and total SAT score do not predict postural control change scores between baseline and re-test in a healthy student-athlete sample as measured by the SOT.

III. Relationship between Motivation and Change Scores

$H_0$3-A: There is not a relationship between average motivation and neurocognitive change score between baseline and re-test in a healthy student-athlete sample as measured by CNS Vital Signs.

$H_0$3-B: There is not a relationship between average motivation and postural control change score between baseline and re-test in a healthy student-athlete sample as measured by the SOT.

Alternate Hypotheses

I. Baseline Performance

H_A1-A: Baseline motivation index score, hsGPA, and total SAT score predicts neurocognitive performance for all domains at baseline in a healthy student-athlete sample as measured by CNS-VS.

H_A1-B: Baseline motivation index score, hsGPA and total SAT score predicts postural control performance at baseline in a healthy student-athlete sample as measured by the SOT.

H_A1-C: Baseline motivation index score, hsGPA and total SAT score predicts acute postural control practice effects between trials one and three on conditions three through six of the SOT in a healthy student-athlete sample.

II. Practice effect Between Baseline and Re-Test Sessions

H_A2-A: Average motivation index, hsGPA and total SAT score predicts neurocognitive change scores for all domains between baseline and re-test in a healthy student-athlete sample as measured by CNS-VS.

H_A2-B: Average motivation index, hsGPA and total SAT score predicts postural control change scores between baseline and re-test in a healthy student-athlete sample as measured by the SOT.

III. Relationship between Motivation and Change Scores

H_A3-A: There is a negative relationship between average motivation and neurocognitive change score between baseline and re-test in a healthy student-athlete sample as measured by CNS Vital Signs.

H_A3-B: There is a negative relationship between average motivation and postural control change score between baseline and re-test in a healthy student-athlete sample as measured by the SOT.

Operational Definitions

a. Domains Tested by CNS Vital Signs Test Battery – the raw score from each domain is then converted to a standard score, which will be used in all the analyses of the domains. The raw score is compared to a normative age-related sample of 100. There are 10 age groups; most of the student-athletes tested will fall in the 15 – 19 age range or the 20 – 29 age range. All standard scores are devised such that higher scores are reflective of better performance.

I. Verbal Memory Domain Score – comprised of results from verbal memory test (VBM), which measures the ability to recognize and remember words.

- This score is calculated using the following equation: VBM Correct Hits Immediate + VBM Correct Passes Immediate + VBM Correct Hits Delay + VBM Correct Passes Delay

II. Visual Memory Domain Score – comprised of results from the visual memory test (VIM), which measures the ability to recognize and remember geometric figures.

- This score is calculated through the following equation: VIM Correct Hits Immediate + VIM Correct Passes Immediate + VIM Correct Hits Delay + VIM Correct Passes Delay

III. Psychomotor Speed Domain Score – comprised of results from the Finger Tapping Test (FTT) and the Symbol Digit Coding Test (SDC), which when combined measures the ability to recognize and process information.

- This score is calculated as FTT Right Taps Average + FTT Left Taps Average + SDC Correct Responses.

IV. Reaction Time Domain Score – comprised of results from The Stroop Test (ST), which measures how fast the participant can react to simple and increasingly difficult instructions.

- This score is calculated as (ST Complex Reaction Time Correct + ST Reaction Time Correct) / 2.

V. Complex Attention Domain Score - comprised of results from The Continuous Performance Test (CPT), Shifting Attention Test, and The Stroop Test (ST), which when combined measures how well focus can be maintained with accuracy. Lower numbers for this domain are better.

- This score is calculated as ST Commission Errors + Shifting Attention Test Errors + CPT Commission Errors + CPT Omission Errors

VI. Cognitive Flexibility Domain Score – comprised of results from The Shifting Attention Test that measures how well the participant is able to adapt to a rapidly changing and complex set of instructions.

- This score is calculated as Shifting Attention Test Correct Responses – Shifting Attention Test Errors – ST Commission Errors

VII. Processing Speed Domain Score – comprised of results from the SDC test, which measures the speed and accuracy of relatively simple learned tasks.

- This score calculated as SDC Correct Responses - SDC Errors.

VIII. Executive Functioning Domain Score – comprised of results from The Shifting Attention Test, which measures how well a participant recognizes shifting and abstraction and the management of multiple tasks.

- This score is calculated as The Shifting Attention Test Correct Responses –

Shifting Attention Test Errors.

IX. Reasoning Domain Score – comprised of results from the nonverbal reasoning test (NVRT) which measures how well the participant can understand the meaning of visual or abstract information and recognizing the relationships between these concepts.

- This score is calculated as the NVRT Correct Responses – NVRT Errors.

b. Academic Profile

I. High School Cumulative GPA

hsGPA: scores will be taken from classes taken during the participant's high school career. Each class taken is given 4 credit points. Earned points will be awarded as follows: A- A-: 4 points, B+ - B-: 3 points, C+ - C-: 2 points, D+ - D-: 1 points, F: 0 points. No extra points will be rewarded for honors or advanced placement classes. All earned points will be summed and divided by the total credit points. This information will be obtained from the Registrar's office.

- Total high school earned points / total high school credit points = hsGPA

II. Scholastic Achievement Test (SAT) total score

The SAT is a widely used college admission test which is divided into three parts, critical reading, writing and mathematics. Each section of the test is worth 800 points each for a total of 2400. The test is scored by the number or correct responses with a deduction of a quarter of a point for every incorrect response. This information will be obtained from the Registrar's office.

b. Motivation Index

i. Motivation index score: This score will be derived from a common test-taking effort exam, Rey's Dot Counting Test. The motivation index score at baseline will be added to the motivation index score at re-test and divided by two to create the average motivation index score.

1. Rey's Dot Counting Test (DCT): Participants are first shown six cards with dots that are organized in a group and then six cards with dots that are not organized in a group (ungrouped) (Appendix A). The participant will tell the test administrator the number of dots on each card as quickly and as accurately as possible. When the participant has correctly identified the number of dots on the card, the investigator will flip to the next card. The test will proceed until the participant has correctly identified the number of dots on all cards. The investigator records the time taken to correctly count the grouped and ungrouped dots and records the number of errors committed by the participant (number of time they incorrectly guess the number of dots).
2. Motivation Index Score- The Motivation Index Score will be computed as the average amount of time taken to count the grouped dots + the average amount of time taken to count the ungrouped dots + total number of errors committed during the DCT at baseline.
3. Baseline Motivation Index Score- The Motivation Index Score recorded during the baseline session.
4. Average Motivation Index Score- The average of the baseline and re-test Motivation Index Score.

c. Postural Control

i. Sensory Organization Test (SOT): The SOT is sophisticated measure of postural control. The participant stands on two force plates facing forward within a visual surround. The machine then calibrates according to the participant's "sway referencing". Sway referencing tilts the force plates anteriorly and posteriorly in order to directly follow the participant's center of gravity sway such that the surface of the force plates remains constant in relation to the center of gravity angle.

- Condition 1: The participant stands with their eyes open on the fixed force plates with a fixed surround.
- Condition 2: The participant stands with their eyes closed on fixed force plates with a fixed surround.
- Condition 3: The participant stands with their eyes open on fixed force plates and sway referenced visual surround.
- Condition 4: The participant stands with their eyes open on sway referenced force plates and with a fixed surround.
- Condition 5: The participant has their eyes closed standing on a sway referenced force plates and fixed surround.
- Condition 6: The participant stands with their eyes open with a sway referenced force pate and sway referenced surround.

The composite score is calculated from 14 of the equilibrium trial scores from each of the six conditions. It is calculated as an average of the mean of Condition 1, the mean of Condition 2 and the individual trial scores from Conditions 3 – 6.

Assumptions

I. Student-athlete was motivated during SAT test session

II. Unweighted High School GPA is comparable across high schools

III. Participants were not distracted while taking any part of the clinical concussion measures.

IV. Participants were honest in completing the demographic questionnaire screening for inclusion and exclusion criteria

V. Sleeping patterns were not disturbed before the baseline or re-test session.

Limitations

I. Results do not apply to individuals who took the American College Test (ACT)

II. Variability of the difficulty of classes taken in high school

III. Results do not apply to different neurocognitive test batteries other than CNS VS

IV. Results do not apply to different postural control tests other than the SOT

V. The participants may not represent a wide range of SAT scores as they were taken from the same university.

VI. Life stresses from baseline to re-test may not have been consistent

Delimitations

I. Participants are student-athletes at the University of North Carolina at Chapel Hill

II. Participants do not have a history of 3 or more concussions (Collins, Grindel et al. 1999)

III. Participants have no previous exposure to CNS VS neurocognitive test battery.

IV. Participants do not have a known learning disability (Beers, Goldstein et al. 1994; Collins, Grindel et al. 1999)

V. Participants are not currently on medication for or have suffered from

   a. Depression

   b. Anxiety

c. Seizures or convulsions (Gualtieri and Johnson 2006)

d. Attention Deficit Disorder (Gualtieri and Johnson 2006)

e. Attention Deficit Disorder with Hyperactivity (Gualtieri and Johnson 2006)

VI. Participants do not have a history of neurologic disorders (Goldberg and Miller 1986; Schretlen, Brandt et al. 1991; Back and Boone 1996)

CHAPTER 2

REVIEW OF LITERATURE

Introduction

Roughly 1.6 to 3.8 million cases of sport-related traumatic brain injuries (TBI) occur in the United States annually (Langlois, Rutland-Brown et al. 2006). Traumatic Brain Injury includes a wide range of injuries, which can include mild concussions to severe brain lesions such as subdural hemorrhages, all of which should be handled by a medical professional. Recent media coverage has focused on popular athletes who have sustained concussions, making the topic a popular point of discussion, not only in the sports medicine community, but in popular culture. Despite recent advancements in concussion research, there is still uncertainty regarding the guidelines that sports medicine professionals use to manage sport-related concussion. The purpose of this literature review is to provide a thorough understanding of sport-related concussion, the mechanisms at play and the importance of its management.

Sports-Related Concussion

Definition

The definition of concussion is now recognized as a complex pathophysiological process affecting the brain due to traumatic biomechanical forces (McCrory, Meeuwisse et al. 2009). Concussions often manifests as a collection of its symptoms and it becomes the responsibility of the sports medicine professional to quickly recognize the signs and symptoms and diagnose the injury (Guskiewicz, Bruce et al. 2004).

Concussions are a type of mild traumatic brain injury (mTBI) for which there exist three different grades. Different sports medicine professionals use different criteria for determining the grade of injury. In the National Athletic Trainers' Association's (NATA) position statement on sport-related concussion, it is acceptable to either determine the grade at the time of injury, at the resolution of symptoms, or disregard the grade completely (Guskiewicz, Bruce et al. 2004).

Epidemiology

Concussions account for roughly 5% of all sports-related injuries in collegiate sports (Hootman, Dick et al. 2007). This number stays fairly consistent when isolating football at both the high school and collegiate level (Guskiewicz, Weaver et al. 2000). In an analysis of the High School Reporting Information Online surveillance system, 76.2% of sport-related concussions in high school resulted from contact with another athlete (Meehan, d'Hemecourt et al. 2010). The same study also reported that 3.3% of the over 500 concussions reported to this database, the athletes were allowed to return to play on the same day. This evidence shows that even with proper identification of the injury as a concussion, athletic trainers are still not following return to play guidelines put forth in position statements made by the NATA.

Mechanism of Injury

Depending on the type of traumatic force sustained, there are three ways to describe the force transmission from the skull to the brain: coup, contrecoup, and skull fracture. The first is a coup injury where the brain's point of injury was located at the point of contact. The second type is a contrecoup injury where the brain's point of injury is opposite in location but equal in magnitude where the point of contact of the skull was. The third type occurs when there is a skull fracture present and there is a depression of a part of the skull into the brain tissue. Neither the coup or contrecoup injury is more severe than the other, rather the most severe is the third type due to the skull fracture (Cantu 1997).

There are three different types of stresses that the brain can undergo when a force is applied to the body that transmits force upon the brain; compressive, shearing and tensile. Compressive forces are the best tolerated and can be described as crushing force. Shearing force occurs when the force is parallel to the stationary surface. Tensile force occurs with the stretching of tissues away from the surface (Guskiewicz, Bruce et al. 2004).

Pathophysiology of Concussion

There are three distinct phases of pathophysiology that occur in the brain that can account for the impairments seen during a TBI. These three phases are: hypermetabolism, hypometabolism, and recovery (Bergsneider, Hovda et al. 2001; Giza and Hovda 2001). The first phase is a hypermetabolism of glucose, which normally lasts for a few hours. This is due to axonal stress, which causes a shift in membrane potential due to an increase in calcium ions and a decrease of potassium. This change in membrane potential causes an increase in activity of the sodium-potassium pump, which explains this hypermetabolism. It is during this phase that the brain is most vulnerable and where it is important for sports medicine professionals to intervene and have the individual discontinue play as further injury can increase the severity of the initial injury. The second phase is marked by a glucose metabolism depression, putting the brain in a state of energy crisis, resulting in the common symptoms of concussion. This phase can last for a number of days. The third phase is metabolism recovery. It has been seen to take an average of 30 days until the start of the third phase of recovery in a severe head injured sample (Bergsneider, Hovda et al. 2001).

Signs and Symptoms

Some common signs and symptoms of concussions are: tinnitus, poor balance, photophobia, phonophobia, headache, nausea, altered state of consciousness, concentration problems, blurred vision and dizziness (Guskiewicz, Weaver et al. 2000). Loss of consciousness is no longer a requirement in the diagnosis of concussions, though it was for a long period of time. Also, the severity of any symptom(s) is highly variable to the individual. This is in light of research that found that over 80% of concussions sustained in high school football do not result in a loss of consciousness and a similar percentage do not result in any post traumatic amnesia (Guskiewicz, Weaver et al. 2000). When looking across sports, less than 5% of concussions at the high school level resulted in a loss of consciousness (Meehan, d'Hemecourt et al. 2010). The serial documentation of the patient's symptoms is important in understanding the amount and type of injury that was sustained (Guskiewicz, Bruce et al. 2004). Drastic or fast changes in mental status are indicative of more serious injuries that are medical emergencies. Tools like a Graded Symptom Checklist (Appendix A) are useful in quantifying the severity of the symptoms and the amount of symptoms seen.

In an investigation of concussions seen in the National Football League, roughly 27% reported cognitive changes and about 40% report memory impairments (Pellman, Powell et al. 2004). At the high school level, 93.4% of concussions resulted in a headache and over half of all concussion symptoms resolved within 3 days, with roughly 70% resolving within the week (Meehan, d'Hemecourt et al. 2010).

Clinical Concussion Measures

Since concussion can affect a number neurocognitive functions and sensory systems, it is important for the sports medicine professional to address and identify any impairment that the athlete may have in each of the systems. The multifaceted approach suggested by the research community includes an on-field assessment of mental status, an inventory of their symptoms, and evaluation of neurocogntition and postural control (Guskiewicz, Bruce et al. 2004). The two aspects of sport-related concussion investigated in this study are postural control and neurocognitive testing.

Baseline Testing

Baseline testing is an important component in the evaluation of concussions as it allows clinicians to understand what is 'normal' for that individual. Baseline concussion testing consists of postural control, symptom checklist, and neurocognitive testing (NCT). Student-athletes are often informed that this testing will be completed again if they sustain a concussion and return-to-play decisions are made based on these measures. There has been a great deal of research relating to factors that influence baseline testing as it has become standard in most sports medicine programs upon recommendations from the NATA (Guskiewicz, Bruce et al. 2004).

Mental Status Testing

The mental status exam is the initial evaluation done on an injury that a sports medicine professional suspects to be a concussion. This type of testing focuses on specific domains of neurological functioning. Mental status is most typically evaluated using the Standardized Assessment of Concussion (SAC). The domains tested are orientation, immediate memory, delayed recall, and concentration. This can be administered in the field while still maintaining fairly high specificity and sensitivity (McCrea 2001).

Postural Stability

Postural control is created by ensemble coding of three major sensory systems, the vestibular, visual, and somatosensory. The somatosensory system is responsible for basic kinesthetic information and orientation of the base of support to the support surface. The visual system is responsible for acquiring the orientation of the eyes and head in relation to surrounding objects (Nashner and Berthoz 1978). The vestibular system is responsible for understanding angular and linear acceleration of the head through the semicircular canals and the utricle and saccules. The vestibular system is also used in the presence of body movement to keep the eyes fixed on a stationary object (Nashner 1972)All of the information gathered by each of these systems are then processed by the cerebellum, these are the afferent pathways of postural control. The cerebellum coordinates this information then uses the efferent pathways, which is comprised of the alpha motor neurons in the skeletal muscles and the brainstem and spinal cord, which then produces the balance corrections. (Guskiewicz 2003). For most healthy adults, the preferred sensory system used for balance control is the somatosensory system (Nashner, Black et al. 1982). The vestibular system and the visual systems when isolated, show a delay between the onset of a perturbation and correction (Nashner 1972; Nashner and Berthoz 1978).

The central nervous system’s contribution to postural control can be divided into two processes: sensory organization and muscle coordination. Sensory organization has been defined as the processes that determine timing, direction and amplitude of corrective postural adjustment based upon information obtained from the three sensory systems involved with postural control. The muscle coordination component determines the temporal sequencing of the muscular contractions to maintain upright posture (Guskiewicz 2003; Guskiewicz 2011).

The most common clinical concussion measure of postural stability is the Balance Error Scoring System (BESS) (Notebaert and Guskiewicz 2005). The BESS consists of 20-

second trials of balance of three stances on a firm and once on a foam surface with the participant's eyes closed. The clinician evaluates balance by counting the number of errors such as lifting their hands from their hips, eyes opening, or lifting the forefoot or heel committed by the athlete during each balance trial. All that is needed to complete this testing is a foam pad, a stop watch, and knowledge of the scoring procedures which is sensitive enough in identifying individuals who have had a history of concussion (Riemann and Guskiewicz 2000).

In recent years, researchers have developed more sophisticated equipment that can objectively quantify postural control deficits through isolating each of the sensory organs. However, this balance exam are cost prohibitive and therefore is not widely used in most sports medicine settings. The Sensory Organization Test consists of six testing conditions performed on a tilting force plate with a tilting visual surround. The Sensory Organization Test has been used on a variety of patient populations outside of the sports medicine field as a clinical measure of balance (Notebaert and Guskiewicz 2005). Each of the six conditions strives to challenge each of the sensory systems to identify which systems may have been affected by the head injury. The individual must ignore the sway-referenced sensory system being challenged in each condition. Each condition is repeated three times and the software provides the clinician with an equilibrium score for every trial and every condition. The equilibrium scores from each of the trials show a comparison of the peak amplitude of anterio-posterior sway to the theoretic limit of stability (Guskiewicz 2003). The software then computes a composite score which weights the scores from each of the conditions for an overall postural control performance score.

With serial administration of this type of evaluation, it has been suggested that individuals improve performance over time (Wrisley, Stephens et al. 2007). However, the factors that contribute to this improvement have yet to be investigated. Using the SOT, it has been observed that concussed athletes experience decreased postural stability until three days after injury (Guskiewicz, Riemann et al. 1997). It seems possible that athletes who are more test-wise may be better able to identify the sway-referencing properties of visual surround and surface (Sarnacki 1979). An athlete who determines that their sway influences the movement of the screen around them and floor beneath them would likely restrict their movements to limit the amount sway-referenced movements. This could present as a better overall composite score or as slight improvements between trials as the athlete becomes wise to the test conditions. It has been suggested that in order for the SOT to provide reliable results for the ES of each condition, two test sessions on the same day in a male student-athlete population must be administered (Dickin and Clark 2007). Moreover, a randomized testing sequence has been proven to provide less reliable results for specific ES of each of the conditions in the collegiate recreationally active population (Dickin 2010). Though the reasons for these acute practice effects between each of the trials of the specific conditions of the SOT have not yet been investigated among collegiate student-athletes. It has been theorized that deficits in sensory integration are responsible for declines in postural control observed post-concussion and the three sensory systems cannot be integrated properly, such that they cannot ignore the sway-referenced system being challenged.(Guskiewicz 2003)

Graded Symptom Checklist

A graded symptom checklist is a list of common symptoms that allows the patient to report and quantify the severity of a symptom this is completed both at baseline and post concussion testing. There is not a threshold at which it is indicative of a concussion, rather when compared to a baseline from the same athlete, could illuminate the extent of injury sustained (Piland, Motl et al. 2003). Like many of the other clinical measures of concussion, it is important to evaluate individuals who exhibit unusually high baseline symptom scores as it may be indicative of other neurological problems (Piland, Ferrara et al. 2010). Checklists have roughly 20 items and are numbered from zero to four or six depending on the scale used. The patient must be honest in order for the checklist useful to the clinician. Many computerized NCT batteries have a graded symptom checklist built into the software as a part of the software for the clinicians.

Neurocognitive Testing

Neurocognitive testing (NCT, also commonly referred to as neuropsychological testing, is used in the sports medicine field to quantify an individual’s neurological functioning. Neurocognitive testing refers to specific tests that evaluate a specific domain of neurological functioning or whole test batteries that evaluate a variety of domains. Computerized NCT batteries have significantly aided the availability of NCT in the sports medicine setting. Cutting down on the test administrator’s duties has allowed an increased number of athletes in various levels of play to be baseline tested. This is not to suggest that paper and pencil tests are any less sensitive or valid, rather the use of computerized NCTs is more popular in the sports medicine setting.

There are a number of factors that can affect NCT performance, such as: previous concussions, educational background, age, medications taken at the time of testing, test anxiety, sleep depravations, and learning disabilities (Beers, Goldstein et al. 1994; Grindel, Lovell et al. 2001; Gualtieri and Johnson 2006). Also, it has been found that there are gender differences in NCT performance for the verbal and visual memory tests, processing speed, mental tracking, and verbal initiation (Barr 2003; Covassin, Swanik et al. 2006). Baseline testing has been proven to be affected by the psychological distress experienced by the participant, especially conditions like depression, anxiety, substance abuse can affect test performance (Bailey, Samples et al. 2010). Factors such as biopsychosocial differences and racial background have been proven to not be a factor in baseline test performance (Solomon and Haase 2008; Shuttleworth-Edwards, Whitefield-Alexander et al. 2009; Kontos, Elbin et al. 2010).

Management

The NATA's position statement suggests that after the sports medicine professional recognizes that an athlete has sustained a sport-related concussion the athlete should be immediately removed from activity, their level of consciousness, a graded symptom score and vital signs (heart rate, blood pressure, and respiratory rate) be taken every 5 minutes to ensure that the injury sustained is not more serious than initially thought (Guskiewicz, Bruce et al. 2004). It is especially important to explain to the athlete that they have sustained a concussion and what they can expect due to the injury that they have sustained. Communication between the sports medicine professional and the athlete and their possible caretakers or guardians is essential.

When an injured individual is asymptomatic, neurocognitive and postural control measures have returned to baseline, and normal neurological functioning has been established, a gradual return-to-play can be implemented beginning with light cardiovascular exercises. When light cardiovascular exercise can be tolerated without concussive symptoms, the individual may be allowed to do more sport-related activity that does not allow the individual to be vulnerable to any head impact.

Motivation

To our knowledge, only two major articles that have addressed motivation related to sport-related concussion assessment, which is a very important facet in NCT performance in sport-related concussion. Bailey et al. found that individuals with high motivation at baseline and post concussion testing exhibited more consistent baseline to re-test results than individuals with suspect motivation (Bailey, Echemendia et al. 2006). However, the sample was drawn from baseline test results and not from motivation specific testing tools. The two groups were determined through individuals who performed well or poorly on a specific test in the battery. It also found a positive relationship between SAT scores and motivation however; this relationship could be purely due to differences in cognitive ability rather than the motivation that an individual put forth during the baseline testing. The study also did not discern between degrees of concussion and did not stipulate a resolution on symptoms before testing could take place, which could have greatly affected the results. The more recent of the two articles utilized separate motivation testing, the Rey-15 Item Test and the Rey Dot Counting Test, a brief paper-and-pencil neuropsychological test battery, and the SAC in a high school setting. The study found that athletes with poor motivation also performed poorly on the SAC (Hunt, Ferrara et al. 2007). A major limitation of the study was that its poor group only had 22 individuals.

It is important to note that there has been no previous research that has investigated the effects of motivation on postural control measures. The investigators of this study believe that motivation levels can affect performance on all clinical measures of concussion.

Student-Athlete's Academic Profile

Although there is an anecdotal relationship between intelligence and academic profile, they are recognized in education literature as two separate domains. SAT score and hsGPA are being used in this study as a part of academic profile information. There has been strong evidence to show a relationship between working memory, an extensive theory in motor learning literature and academic performance (Aronen, Vuontela et al. 2005; St Clair-Thompson and Gathercole 2006). Working memory refers to the short-term storage and manipulation of information, which is commonly used in NCTs. Of interest in this study is the abilities of the visuospatial sketch pad which not only encompasses visual information such as color and form but also spatial movements which may be involved with kinesthetic movements (Baddeley 1986; Baddeley 2007).

High School Grade Point Average

High school grade point average (hsGPA) has not been commonly used in the sport-related concussion literature. There is only one article that even mentions a collegiate GPA as a part of its discussion (Miller, Adamson et al. 2007). This may be due in large part to the relativity in the meaning of hsGPA, as it is heavily based on the differences between students in different schools and states. This is due in part to the types of classes taken by individuals and the different requirements that different schools may have. This can greatly influence an individual's hsGPA. There has yet to be a study that has investigated the effects or influences of hsGPA on NCT.

Scholastic Assessment Test

Current research has not come to a consensus when it comes to the possibility of a relationship between scholastic performance and NCT performance. Previous studies have utilized an older form of the SAT that is no longer relevant to the current population of collegiate student-athletes, since it was changed in 2005. The SAT's format and scoring change has focused on moving away from intelligence testing, and more toward an acquired knowledge format along with the addition of an essay section that is worth an additional 800 points, making the whole test out of 2400 points (Camara and Echternacht 2000). It has been shown that previous exposure to a concussion does not affect scholastic ability; in fact, a study found that individuals who have had 2 or more TBIs had the highest average SAT score in the sampled population (Brown, Guskiewicz et al. 2007).

In a study by Echemendia et al, it was determined that SAT was not a significant covariate for the baseline testing performance between injured and control participants. The use of the SAT scores was cited as a means “to control for the effects of general cognitive ability in the neuropsychological test scores” (Echemendia, Putukian et al. 2001). The data analyzed were from baseline testing which had the SAT total score as a part of a multivariate analysis of covariance. The neuropsychological test battery used was a pencil and paper evaluation. The analysis was not completed for the change scores or for the summary scores after repeat test administration, instead, the two groups just failed to show a significant relationship to SAT total score before injury. Furthermore, the SAT scores used for this analysis were from the original SAT test out of 1600 points and not 2400 points, as will be analyzed in this study.

It has been suggested that individuals with higher hsGPA and SAT scores exhibit increased practice effects in test/re-test results than individuals with lower hsGPA and SAT scores (Miller, Adamson et al. 2007). This study suggests that these individuals have more “test-wiseness” and thus are able to perform better at re-test than individuals with lower hsGPA and SAT scores on neurocognitive testing. This same theory can be applied to physical tasks such as SOT performance as suggested by the visusopatial sketch pad of the working memory theory (Baddeley 1986; Baddeley 2007). As stated earlier in the paper, the program uses “sway referencing” and individuals who are able to understand this through the testing, are able to increase their ES.

Motivation has been proven to share a positive relationship with final course grades, such as those used to compute hsGPA (Fortier, Vallerand et al. 1995). Motivation has been found to be a very strong factor in success for individuals who have been identified as “gifted” (Terman and Oden 1959; Feldhusen 1986; Haensly, Reynolds et al. 1986). The term gifted is often in reference to individuals with increased cognitive ability as compared to the general public by the educational research community. Researchers found that the success that gifted individuals have is strongly affected by their motivation to perform in the academic arena (Terman and Oden 1959). Wong and Csikszentmhalyi assert that the motivation for high school students is low for short term performance but is more geared toward the long term goal of getting “good grades” such as those seen in the hsGPA (Wong and Csikszentmihalyi 1991).

In a study completed in 2004, it was found that 9% of the variance in collegiate academic success was to the student-athletes’ academic motivation, American Collegiate Testing (ACT) score, and race (Gaston-Gayles 2004). This findings of this study is opposed to the prevailing belief in educational literature that motivation does not affect academic performance in collegiate student-athletes (Sellers 1992). The 2004 study failed to use hsGPA, which is commonly used in predictor models and which will be used in this study, which could explain for the result of only 9% of explained variance. Standardized test score such as the SAT total score or ACT score and hsGPA has been proven to be strong predictors of collegiate success (Camara and Echternacht 2000). Collegiate academic success was computed as the student-athlete's current collegiate GPA.

The cognitive ability and motivation during testing have been cited as two factors that can affect baseline and re-test performance that researchers have struggled to control in many research designs. The relationship that these two factors have to each other is also apparent, as the hsGPA measure is affected by long-term motivation and the SAT total score is affected by short-term motivation. By isolating these two co-factors to NCT performance, an evaluation for the use of these two factors in future research can be made.

Methodological Considerations

Sensitivity and Specificity of the Dot Counting Test

There have been only two studies that have utilized the Dot Counting Test (DCT). The DCT is commonly used in neuropsychological settings in the detection of malingerers. It was found that the Dot Counting Test was sensitive enough to detect simulators from non-simulators (Binks, Gouvier et al. 1997). The testing procedures was also found to be sensitive and specific enough to identify suspect motivation individuals with a head injury and other various neurological injuries (Boone, Lu et al. 2002).

Reliability and Validity of CNS Vital Signs Neurocognitive Test Battery

There has been one study to address the reliability and validity of the test battery to be used in this study: CNS Vital Signs Neurocognitive Test Battery (CNS-VS). The test battery consists of 8 separate tests: Verbal Memory, Visual Memory, Finger Tapping, Symbol Digit Coding, Stroop, Shifting Attention, Continuing Performance, and Reasoning tests. From these 8 tests, the computer program is able to test 10 domains of neurocognitive functioning: Neurocognitive Index, Composite Memory, Verbal Memory, Visual Memory, Psychomotor Speed, Reaction Time, Complex Attention, Cognitive Flexibility, Processing Speed, Executive Functioning and Reasoning Domains. The authors Gualiteri and Johnson found that the test battery is not only reliable and valid in identifying individuals with mild cognitive impairment and early dementia, post-concussion syndrome and severe brain injury, children and adolescents with Attention Deficit Disorder and patients with depression from unmatched controls (Gualtieri and Johnson 2006).

Reliability and Validity of the Sensory Organization Test

The SOT has been found to have an intraclass correlation coefficient (ICC) of 0.66 which is moderate test-retest reliability for the composite score in an elderly population (Ford-Smith, Wyman et al. 1995). In a similar study completed on a young adult population, a similar ICC was found for this population as well between the first and second test sessions (Wrisley, Stephens et al. 2007). The SOT has been found to be sensitive to changes in dynamic postural control (Hamid, Hughes et al. 1991).

Purpose

Since the introduction of computerized NCTs to the sports medicine community, there has been much research on many of the factors that affect NCT performance. For the most part, research has focused on post-morbid NCT performance. It has been suggested by many in the research community that baselines are only as "good" as the effort the individual puts into the test session (Hunt, Ferrara et al. 2007; Randolf 2011). And it has already been determined that as motivation increases, NCT performance increases the amount of change in motivation accounts for has yet to be seen (Bailey, Echemendia et al. 2006; Hunt, Ferrara et al. 2007). Researchers have observed that both scholastic performance as reflected in grade point average and scholastic ability as reflected in the Scholastic Assessment Test (SAT) score are a factors in neurocognitive performance (Echemendia, Putukian et al. 2001; Brown, Guskiewicz et al. 2007). While this information has been reported in the above studies in an effort to describe their sample, academic profile has yet to be investigated to affect computerized NCT performance. Moreover, it has been observed that scholastic performance and scholastic ability may have been a factor in serial NCT performance in healthy individuals (Miller, Adamson et al. 2007). The purpose this research is to understand and possibly account for the some changes seen in serial clinical concussion measures in healthy individuals, as it will help clinicians understand the changes seen in an injured population.

CHAPTER 3

METHODS

Introduction

Clinical evaluation of concussion begins at baseline. Baseline testing is an important part of the process as it provides individualized information on each athlete, aiding clinicians to make appropriate decision regarding when an athlete is ready to return to play. Upon recommendation by the National Athletic Trainers' Association (NATA), most sports medicine programs utilize a multifaceted concussion assessment including a thorough clinical evaluation, postural control, symptom score, and neurocognitive testing (Guskiewicz, Bruce et al. 2004; McCrory, Meeuwisse et al. 2009). It is important for clinicians to obtain valid baseline measures that reflect each athletes' individualize neurocognitive and postural control capabilities as it will play a major role in the management of a concussion. The purpose of this study is to predict baseline and re-test changes in neurocognition and postural control using motivation indices, high school grade point average (hsGPA), and total Scholastic Assessment Test (SAT) score.

Participants

This study is a part of a larger ongoing baseline testing protocol for all incoming student-athletes at the university and for student-athletes who have sustained a concussion in the previous year of play for a re-baseline. There were a total of 165 incoming student-athletes tested at this time. Student-athletes enrolled in this study were either incoming freshmen student-athletes or student-athletes who have transferred to the university. We chose to exclude student-athletes that were repeating baseline testing due to concussive injury in the year prior as they have had prior exposure to the test battery. The test battery consists of a computerized Neurocognitive Test battery (CNS Vital Signs, Chapel Hill, NC), the Sensory Organization Test (Neurocom International, Inc., Clackamas, OR), a demographic questionnaire, and the Rey Dot Counting Test (measure of motivation). Participants also completed a graded symptom checklist, the Holmes and Rahe Stress Index-Revised Social Readjustment Rating Scale, and the Pittsburgh Sleep Quality Index, but these measures were not of interest in this study.

Baseline

This study consisted of 165 healthy student-athlete participants (mean age at baseline: 18.54 ± 0.58) recruited from UNC-CH's NCAA Division I athletic program. Demographic information for athletes that completed baseline testing is presented in Table 2. Participants were excluded if they reported: previous exposure to CNS Vital Signs (CNS-VS), previous exposure to the SOT, a history of three or more concussions, previous diagnoses of learning disability, depression, seizures/convulsions, attention deficit disorder, or attention deficit hyperactivity disorder, or previous treatment for a psychiatric disorder. The screening for inclusion criteria was captured on the demographic information questionnaire completed prior to taking the CNS-VS test battery.

Re-test

All student-athletes who participated in the baseline testing were asked to participate in the re-test session scheduled approximately 10 weeks following their initial baseline session. All student-athletes were contacted via email 2 weeks prior to their 10-week test date and asked to schedule a re-test time. For those who responded with a test time, a reminder email was sent 1 week prior to their scheduled testing date. Among the 165 first-year student-athletes that completed baseline testing, 59 returned for follow-up testing which was completed 70±4.5 days from baseline. Demographic information for athletes that completed the re-test is presented in Table 2. Every effort was made to have the participant complete the re-test performance during the same time of day as the baseline session (within 2.25±1.5 hours). Participants were excluded if they sustain a traumatic brain injury (TBI) between baseline to re-test as that may confound their test performance on the NCT battery or the Sensory Organization Test (SOT).

Procedures

This cross-sectional study consisted of two testing sessions all conducted at the Matthew Gfeller Sport-Related Traumatic Brain Injury Research Center.

Baseline

Participants reported to the baseline testing session and signed an informed consent form approved by the university's Institutional Review Board. The participant was informed that they were there to complete baseline testing. They were told that the purpose of this testing was to collect neurocognitive, postural control, and symptom scores from them prior to their season of play so that if they were to sustain a concussion, sports medicine professionals would be able to compare back to these scores that represent their pre-injured state. The participant was then assigned randomly to a counterbalanced test order including the SOT, CNS-VS neurocognitive test battery and graded symptoms checklist. At the start of the CNS-VS test battery the participant filled out a demographic questionnaire (Appendix E). Motivation testing occurred at the end of every participant's testing session, as this is when the investigators believed that motivation would be at its lowest point. Participants were told that motivation testing is a paper and pencil neurocognitive test in order to blind them from our intention to measure their motivation as this may affect the amount of effort given. Participants completed baseline neurocognitive testing in a room with no more than three other athletes concurrently testing. Postural control assessments were completed in a room alone with the investigator. The entire baseline testing session took approximately 60 to 90 minutes for participants to complete. As a part of the informed consent form, there was a line where the participant was asked if they were willing to disclose their hsGPA and SAT information to the investigators of the study. Participants had to place a check mark next to "Yes I do consent" or "No I do not consent" to disclosing the information. If they left both boxes blank, they were contacted at a later time and asked via e-mail if they consent. If they consented to the disclosure of this information their names and university personal identification number (PID) was collected and sent to the registrar's and admissions office to obtain this information. The participant's unweighted hsGPA were taken from their high school final transcripts, which are on file in the admissions office. The PIDs and names were sent to each of the offices and a report was sent to the investigators of the study. The names were then matched to their study specific identification number and then placed into a de-identified data set.

Re-test

Participants returned for the second testing session approximately ten weeks after baseline testing is conducted. Participants were contacted 2 weeks before their 10-week re-test date and asked for the best time to schedule their re-testing. Participants who responded to this email were then sent a reminder email one week prior to their test date and time. They performed the same computerized neurocognitive test battery; balance testing, graded symptom checklist, and Dot Counting Test. Participants were reminded of the instructions of each test. The completed testing session took approximately 60 to 90 minutes for participants to complete.

Instrumentation

Clinical Concussion Measures

CNS Vital Signs Neurocognitive Test Battery

The test battery utilizes eight tests and derives ten different domains from these tests. The Verbal Memory, Visual Memory, Finger Tapping, Symbol Digit Coding, Stroop, Continuous Performance, Shifting Attention, and Reasoning Tests are all used in this testing battery. This battery has been shown to be both reliable and valid in the detection of neurocognitive deficits (Gualtieri and Johnson 2006).

ii. Verbal Memory Test: The participant was given a set of fifteen words to memorize. The words appear on the screen one at a time for two seconds each. After all fifteen words are shown, a larger list of thirty words is presented on the computer monitor one at a time and the participant was instructed to press the spacebar when a word from the original list is shown on the screen. At the end of the test battery (approximately 20-25 minutes later), the participant was shown a different set of thirty words, which includes the fifteen original words the participant was told to memorize on the monitor. The participant was instructed to press the spacebar when a word that was given in the original list is shown.

iii. Visual Memory Test: the participant was shown a set of fifteen geometric shapes to memorize, with the symbols being shown one at a time for two seconds each. Thirty geometric shapes were shown and the participant one at a time and the participant will press the spacebar when a symbol from the original list is shown on the screen. At the end of the test battery (approximately 20-25 minutes later), the participant was shown a different set of thirty geometric shapes, which include the fifteen original geometric shapes the participant was told to memorize on the monitor. The participant was instructed to press the spacebar when a geometric shape that was given in the original list is shown.

iv. Finger Tapping Test: the participant was instructed to use their right index finger to press the spacebar as many times as they can in a ten second period. The participant then does the same thing with their left index finger. The test is scored as an average of the number of taps between the left and right index finger. The participant was given a practice trial for both the left and right index finger before the test is administered.

v. Symbol Digit Coding Test: the participant was shown a key in which numbers 2 – 9 are linked to symbols at the top of the screen. Under the key the participant was given a similar key with the symbols in a random order and blank boxes under the symbols. The participant must correctly type in the numbers that are linked to the symbols. The participant has 120 seconds to answer as many blank boxes as possible. The participant was given one practice screen with 8 trials before the test begins.

vi. The Stroop Test: this test is comprised of the words BLUE, RED, YELLOW, and GREEN showing up on the screen against a white background. For the first condition of this test, the participant was instructed to press the spacebar when any word appears on the screen. The text for this condition appears in black. For the second condition, the participant was instructed to press the space bar when the color of the text matches the word on the screen (e.g. the word green written in green font). For the third condition, the participant was instructed to press the spacebar when the color of the text is not the same as the word shown on the screen (e.g. the word green written in blue font). The first condition generates a simple reaction time score based on the time that it took for the participant to press the spacebar. The correct response times from the second and third conditions create the complex reaction score. Typically, the third condition reaction time is greater than the reaction time from the first and second condition. For all scores generated from this test, lower scores are reflective of higher performance on the test.

vii. Shifting Attention Test: this test utilizes the right and left shift keys on the keyboard. A single geometric shape that is either a circle or a square and colored either red or blue is displayed on the top of the computer screen. The lower portion of the screen displays two additional geometric shapes that are also either a circle or a square and colored either red or blue. Instructions are displayed to either "MATCH COLOR" or "MATCH SHAPE" for that particular test screen. The participant was instructed to press the shift key of the side which matches the condition specified at the top of the screen. The conditions, shapes and colors for all three figures change randomly for ninety seconds. The test collects the number of correct answers given, the number of errors made, and the response time.

viii. Continuous Performance Test: this test utilizes the spacebar key of the keyboard and a black screen with white text. At the beginning of the test, the participant was instructed to press the spacebar only when the letter "B" appears on the screen. A variety of letters was shown to the participant throughout the test which lasts roughly five minutes. Over 200 letters appeared on the screen, forty of which are the letter "B" and 160 of which are other letters. Each minute of the test, the letter "B" appeared 8 times. The test collects the number of correct responses, errors of commission and omission.

ix. Non-Verbal Reasoning Test: this test scored for accuracy and speed and utilizes the number keys 1-5. At the top of the screen was a test grid with two rows and two columns. In the grid there will be one object missing. Below the test grid was the answer grid with 5 columns in a single row numbered 1 through 5. The participant was instructed to press the number key of the object that best fills the blank cell in the test grid. The participant was given two practice trials and then the test was started. The test consists of 15 test grids and the participant was given 14.5 seconds to complete each test grid. The test increases in difficulty as the test goes on. The test was scored by the number of correct responses, the average correct response time, the commission errors, and the omission errors.

Postural Control: Sensory Organization Test

The participant stands on two force plates facing forward within a visual surround with their shoes off. The participant then completes three trials of six different sensory conditions. During some conditions the participant's anterior and posterior sway is "sway referenced". Sway referencing tilts the force plates anteriorly and posteriorly in order to directly follow the participant's center of gravity sway such that the surface of the force plates remains constant in relation to the center of gravity angle. The following are descriptions of each of the six conditions:

Condition 1: The participant stood with their eyes open on the fixed force plates with a fixed surround.

Condition 2: The participant stood with their eyes closed on fixed force plates with a fixed surround.

Condition 3: The participant stood with their eyes open on fixed force plates and sway referenced visual surround.

Condition 4: The participant stood with their eyes open on sway referenced force plates and with a fixed surround.

Condition 5: The participant had their eyes closed and stood on a sway referenced force plates and fixed surround.

Condition 6: The participant stood with their eyes open with a sway referenced force pate and sway referenced surround.

Motivation Index: Rey's Dot Counting Test

The DCT consists of 5x7 index cards with dots placed on them with the first six in an ungrouped then the last six in a grouped manner (Appendix A). The participant was asked to state to the test administrator the number of dots on the card given. The participant was able to use the eraser end of a pencil to aid in counting the number of dots. If the participant did not provide the test administrator with correct number of dots, they were told to recount the dots until the correct number of dots is given. The motivation index score is computed by averaging the amount of time it took to count the grouped dots and ungrouped dots separately then adding that number to the total number of errors committed during the testing. Lower motivation index scores reflect higher levels of motivation while longer times reflect lower levels of motivation. This test has been observed to be valid and reliable as a measure of motivation or effort (Binks, Gouvier et al. 1997; Boone, Lu et al. 2002).

Graded Symptom Checklist

Symptom severity data was collected as a part of the baseline testing program; however this data was not analyzed as a part of this study. The graded symptom checklist is a self-reported score on a scale with different time points with 18 symptoms that are commonly experienced by individuals who have sustained a TBI (Alla, Sullivan et al. 2009). Self-reported checklists have been proven to be both reliable and valid (Lange, Iverson et al. 2010; Piland, Ferrara et al. 2010). Participants were asked to scale their experience of the symptom that occurs on a "regular basis" which is defined as more than three times a week. The scale is from 0 – 6, with 0 representing that the participant does not experience this symptom more than three times a week, 1-2 defined as mild, 3 -4 as moderate and 5 -6 as severe. A list of the symptoms of the symptoms questioned on CNS-VS is provided in Appendix C.

Data Reduction

Academic Profile

High School GPA scores were calculated by the admissions office from classes taken during the participant's high school career. Each class taken was given 4 credit points. No extra points were rewarded for honors or advanced placement classes. All earned points were summed and divided by the total credit points. This information was obtained from the University's Admissions Office (Total high school earned points / total high school credit points = hsGPA).

Total Scholastic Assessment Test score was obtained from an individual's highest SAT subject scores from any test session. It consists of the Writing, Critical Reading, and

Mathematics portions of the SAT I reasoning test, commonly used in undergraduate admissions decisions. Each section of the test is worth 800 points for a total of 2400 points. Every correct response was worth 1 point but incorrect responses were penalized with a quarter point reduction. This information was provided to the investigator via the University's Registrar's Office.

We also contacted participants via email and in-person after baseline and re-test asking them to report their best estimate of their unweighted hsGPA and total SAT score.

Clinical Concussion Measures

Neurocognitive Testing: CNS Vital Signs

Neurocognitive domain standard scores will be computed according to the equations defined in the definitions section of Chapter I.

To address our second research question regarding practice effect, change scores were calculated by subtracting the baseline scores from re-test scores for the CNS-VS standard scores and the SOT composite score (change score=re-test score-baseline score). The average motivation index was be computed by summing the baseline and re-test motivation index scores and dividing by 2.

Domain Validity

We chose to exclude individual domain scores that did not meet validity criteria previously established by CNS Vital Signs. Invalidity criteria were obtained from the CNSVS Interpretation Guide available for download at the following website: https://www.cnsvs.com/index.php/clinical-practice and is outlined in Table 1. below.

Table1. Domain Validity Conditions for CNS Vital Signs Neurocognitive Test Battery

Domain	**Test(s)**	**Condition**
Verbal Memory	Verbal Memory Test	Raw score > 30
Visual Memory	Visual Memory Test	Raw score > 30
Processing Speed	Symbol Digit Coding	Raw score > 20
Executive Functioning	Shifting Attention Test	Correct > Errors
Psychomotor Speed	Finger Tapping Test Symbol Digit Coding	FTT total taps > 40 SDC correct > 20
Reaction Time	Stroop Test	Stroop test reaction time > complex reaction time > simple reaction time
Complex Attention	Stroop Test Continuous Performance Test Shifting Attention Test	Total number of correct responses > the total number or errors on each of the tests
Reasoning	Non-Verbal Reasoning Test	Correct responses > 4

Postural Control: The Sensory Organization Test

The composite score of the SOT is comprised of 14 of the equilibrium scores from each of the six conditions. It is calculated as an average of the (1) mean of Condition 1, (2) the mean of Condition 2 and (3-14) the individual trial scores from Conditions 3 – 6. We excluded outlying SOT composite score values if they were 1.5 times the interquartile range below the 25th percentile. The interquartile range is the range that encloses the middle 50% of the observations.

Motivation Index

The motivation index score was computed for each participant from the time and number of errors committed during the DCT. The motivation index score is comprised of the average grouped time plus the average ungrouped time plus the total number of incorrect responses (Motivation Index = grouped time/6 + ungrouped time/6 + errors). The scale was made such that higher scores are reflective of lower levels of motivation and lower scores are reflective of higher levels of motivation. Average motivation index was computed by summing the baseline and re-test motivation index and dividing by 2.

Data Analysis

All statistical analysis was conducted using SPSS 15.0 (Chicago, IL).

Self-Reported Academic Profile

Due to the insufficient number of unweighted hsGPA and SAT scores obtained from the admissions office, all participants were contacted via email and in-person and were asked to respond by reporting their best estimate of their unweighted hsGPA and total SAT score. 21 athletes responded with their self-reported academic information that we had previously obtained academic information on that had been obtained through the admissions and registrar's office. An intraclass correlation coefficient was computed to determine the reliability between the self-reported hsGPA and SAT and acquired hsGPA and SAT through the registrar or admissions. We found that athletes reliably self-reported hsGPA ($ICC_{2,1}$ = 0.991) and SAT ($ICC_{2,1}$ = 0.933). For 17 athletes for which either hsGPA or SAT were not available through the registrar or admissions office, we utilized their self-reported values.

Research Question 1: Baseline Performance

To address the first part of our first research question (RQ1-A) regarding baseline neurocognitive performance, we employed nine separate multivariate regression models using each baseline CNS-VS standard score as a criterion variable. Baseline motivation index score, SAT total score, and hsGPA were entered into the model as predictor variables using the enter method.

To address the second part of our first research question (RQ1-B) regarding baseline postural control performance, we employed one multivariate regression model using the SOT composite score, as a criterion variable. Baseline motivation index score, SAT total score, and hsGPA were entered into the model as predictor variables using the enter method.

To address the third part of our first research question (RQ1-C) we employed four multivariate regression models using the change score of ES trial 3 – trial 1 for conditions 3 – 6 as the criterion variables. Baseline motivation index score, SAT total score and hsGPA were also entered into the model as predictor variable using the enter method.

Research Question 2: Practice effect Between Baseline and Re-Test Sessions

To address the first part of our second research question (RQ2-A) regarding the practice effect on neurocognitive performance, we employed nine separate multivariate regression models using each CNS-VS standard change scores as a criterion variable. Average motivation index, SAT total score, and hsGPA were entered into the model as predictor variables using the enter method.

To address the second part of our second research question (RQ2-B) regarding the practice effect on postural control performance, we used one multivariate regression model using the SOT composite change score as the criterion variable. Average motivation index, SAT total score, and hsGPA were entered into the model using the enter method as predictor variables.

Research Question 3: Relationship between Motivation Index and Change Scores

To address the first part of our third research question (RQ3-A) regarding the relationship between motivation index and neurocognitive domain practice effect, we employed nine correlations using each CNS-VS standard change score and the average motivation index from baseline and re-test.

To address the second part of our third research question (RQ3-B) regarding the relationship between motivation index and postural control practice effects, we employed one correlation using the SOT composite change score and the average motivation index from baseline and re-test. The data summary located on the next page details the research questions with the predictor and criterion variable for each of the regression models.

Table 2. Data Summary Table

Research Question	Predictor Variable(s)	Criterion Variable(s)	Method
1. *Baseline Performance* A: Do baseline motivation index score, hsGPA, and total SAT score predict neurocognitive performance at baseline in a healthy student-athlete sample as measured by CNS-VS?	-Baseline Motivation Index -total SAT score -hsGPA	The nine baseline CNSVS standard scores	Nine multivariate regression models using the enter method for each of the criterion variables
B: Does baseline motivation index score, hsGPA and total SAT score predict postural control performance at baseline in a healthy student-athlete sample as measured by the SOT?	-Baseline Motivation Index -total SAT score -hsGPA	Baseline SOT Composite score	One multivariate regression model using the enter method
C: Does baseline motivation index score, hsGPA and total SAT score predict acute postural control practice effects between trials one and three for conditions three through four of the SOT in a healthy student-athlete sample ?	- Baseline Motivation Index - Total SAT score - hsGPA	Change scores between trials 1 and 3 on conditions 3 through 6	Four multivariate regression models using the enter method for each of the criterion variables.

Research Question	Predictor Variable(s)	Criterion Variable(s)	Method
2. *Practice Effect between Baseline and Re-test Sessions* A: Does motivation index change score, hsGPA, and total SAT score predict neurocognitive practice effects between baseline and re-test in a healthy student-athlete sample as measured by CNS-VS?	- total SAT score - hsGPA - Average Motivation Index	The nine CNSVS standard change scores	Nine multivariate regression models using the enter method for each of the criterion variables
B: Does motivation index change score, hsGPA, and total SAT score predict postural control practice effects between baseline and re-test in a healthy student-athlete sample as measured by the SOT?	- total SAT score - hsGPA - Average Motivation Index	SOT Composite change score	One multivariate regression model using the enter method for each of the criterion variables
3. Relationship between Motivation Index and Change Scores A: Is there a relationship between average motivation index and neurocognitive domain change score at baseline and re-test in a healthy student-athlete sample as measured by CNS-VS?	- Average Motivation Index between baseline and re-test - The nine domain change scores of CNS-VS		Nine Correlations for each of the domain change score
B: Is there a relationship between average motivation index score and postural control change score at baseline and re-test in a health student-athlete sample as measured by the SOT?	- Average Motivation Index between baseline and re-test - Composite Equilibrium Change Score		One Correlation for the composite equilibrium change score

CHAPTER 4

RESULTS

Research Question #1 *Baseline Performance*

A total of 165 NCAA Division I incoming student athletes were tested as a part of a larger sports medicine original baseline testing protocol. These student-athletes were used in the analysis of the first research question. Of the total number tested, 25 athletes did not consent to the release of their unweighted cumulative high school grade point average (hsGPA) and Scholastic Achievement Test (SAT) information to the investigators of the study. Of the remaining 140 athletes, we were able to obtain both hsGPA and SAT from the registrars and admissions office for 77 athletes. For 17 athletes whose hsGPA were not available we used their self-reported unweighted hsGPA. Of the remaining 94 student-athletes, only 86 student-athletes met the inclusion criteria. Participants that presented with invalid scores, as detailed in the data reduction section in Chapter 3, were excluded from specific domain analyses. Two participants were found to have invalid scores for the psychomotor speed domain, three for reaction time, seven for reasoning domain, and four for postural control testing.

A total of ten multivariate regression models were performed, using baseline motivation index, hsGPA, and total SAT score, as the predictor variables using the enter method. Demographic information for athletes included in analyses for research question 1 is reported in Table 2. Descriptive statistics for the criterion variables are reported in Table 3. Descriptive statistics for predictor variables are reported in Table 4. Statistical results for the nine regression models are reported in Table 5. Multiple regression coefficients are reported in Table 6.

Unweighted hsGPA was a significant predictor of the processing speed standard score ($F_{3,82}$=3.73, p = 0.014; R^2=0.12). Total SAT score was a significant predictor of the complex attention standard score ($F_{3,82}$=3.32, p = 0.024; R^2=0.11) and the Sensory Organization Test (SOT) composite score ($F_{3,78}$=6.31, p = <0.001; R^2=0.20). However, the model explained only 12% of the variance in the processing speed standard score, 11% of the variance in the complex attention standard score, and 20% of the variance in the SOT Composite score.

Baseline motivation index, hsGPA, and total SAT score were not significant predictors for the domains of verbal memory ($F_{3,82}$=.0.69, p = 0.560; R^2=0.03), visual memory ($F_{3,82}$=0.66, p = 0.578; R^2=0.02), psychomotor speed ($F_{3,80}$=0.64; p = 0.591; R^2 = 0.02) reaction time ($F_{3,79}$=0.07, p = 0.977; R^2=0.003), cognitive flexibility ($F_{3,82}$=1.16, p = 0.330; R^2=0.04), executive functioning ($F_{3,82}$=1.12, p = 0.345; R^2=0.04), and reasoning ($F_{3,75}$=1.82, p = 0.151; R^2=0.07). Likewise, our model did not predict equilibrium change scores between trials 1 and 3 for condition 3 ($F_{3,80}$=1.60, p = 0.197, R^2 = 0.06), condition 4 ($F_{3,79}$=0.27, p = 0.849, R^2 = 0.01), condition 5 ($F_{3,81}$=0.28, p = 0.841, R^2 = 0.01), condition 6 ($F_{3,80}$=0.73, p = 0.538, R^2 = 0.03).

Research Question #2 *Practice effect between Baseline and Re-Test Sessions*

A total of 59 participants returned for follow-up testing roughly 10 weeks after baseline. Of the participants who returned, the investigators had already obtained hsGPA and total SAT score for 36 participants. Demographic information for the athletes that returned for follow-up testing are reported in Table 2. Descriptive statistics for the criterion variables (Session Two scores and Change Scores) are reported in Table 3. Descriptive statistics for the predictor variables are reported in Table 4. The statistical results for the ten regression models are reported in Table 7. Multiple regression coefficients are reported in Table 8.

Average motivation index, hsGPA, and total SAT score did not significantly predict any of the change scores in neurocognitive and postural control performance between baseline and re-test ($p > 0.05$).

Research Question #3 *Relationship between Motivation Index and Change Scores*

Of the 59 participants who returned for the Session Two testing, a total of 51 participants met the inclusion criteria and were used in the correlation analyses performed between the participants' average motivation index and the change scores for each of the domains. The Pearson Correlation coefficients for each of the domains are reported in Table 9. We observed a low positive relationship between the executive functioning change score and average motivation index score ($R=0.28$, $p = 0.05$). We did not observe any other significant relationships between average motivation index and any other outcome measures.

Table 3. Demographic Information for baseline and change score samples

	Baseline		Re-Test	
Male (n)	50		21	
Female (n)	38		32	
	Mean	SD	Mean	SD
Height (in)	69.16	5.02	67.59	4.53
Weight (kg)	167.23	44.72	154.95	35.87
Age (years)	18.58	0.52	18.55	0.45

Table 4. Descriptive statistics for all baseline and session two neurocognitive and postural control variables (criterion variables)

	Baseline			Re-Test			Change Scores*		
	n	Mean	SD	n	Mean	SD	n	Mean	SD
CNSVS Standard Score									
Verbal Memory	86	97.98	19.45	56	100.80	21.79	51	0.37	20.03
Visual Memory	86	99.50	16.22	56	103.30	17.26	51	1.43	16.75
Psychomotor Speed	84	105.86	11.13	56	110.07	12.34	51	5.47	10.79
Reaction Time	83	101.30	13.67	56	105.91	13.05	44	5.02	12.64
Complex Attention	86	95.07	36.40	55	89.56	66.69	50	-0.06	28.75
Cognitive Flexibility	86	98.97	14.48	55	104.07	11.74	50	2.67	9.62
Processing Speed	86	103.73	15.57	56	111.09	16.42	52	6.87	15.68
Executive Functioning	86	99.38	13.75	56	105.14	11.03	53	4.06	9.92
Reasoning	79	99.42	13.72	56	101.29	15.24	47	5.32	15.64
Sensory Organization Test									
Composite Score	82	76.90	7.07	56	81.76	5.80	51	5.43	6.00
Condition 3 Change Score	80	-2.71	6.76						
Condition 4 Change Score	79	11.46	20.34						
Condition 5 Change Score	81	7.84	16.42						
Condition 6 Change Score	80	6.78	18.85						

*Research Question 2 only uses individuals who have SAT and unweighted hsGPA available to the researchers.

Table 5. Descriptive Statistics for Research Question 1 and 2 predictor variables

	Baseline		Re-Test	
	Mean	SD	Mean	SD
Motivation Index Score	11.61	2.96	10.25	2.67
Unweighted hsGPA	3.57	0.34	3.64	0.27
Total SAT Score	1702.33	263.38	1764.72	183.90
Average Motivation Index Score†			10.84	2.00

† Average across baseline and session two

Table 6. Statistical Results for Baseline Multiple Regression Models

	F Value†	p	R^2
CNSVS Standard Score			
Verbal Memory	0.69	0.560	0.03
Visual Memory	0.66	0.578	0.02
Psychomotor Speed	0.64	0.591	0.02
Reaction Time	0.07	0.977	0.003
Complex Attention	**3.32**	**0.024***	**0.11**
Cognitive Flexibility	1.16	0.330	0.04
Processing Speed	**3.73**	**0.014***	**0.12**
Executive Functioning	1.12	0.345	0.04
Reasoning	1.82	0.151	0.07
Sensory Organization Test			
Composite Score	**6.31**	**<0.001***	**0.20**
Condition 3 Change Score	1.60	0.197	0.06
Condition 4 Change Score	0.27	0.849	0.01
Condition 5 Change Score	0.28	0.841	0.01
Condition 6 Change Score	0.73	0.538	0.03

† All regression models had 3 degrees of freedom Predictor variables were baseline motivation index score, unweighted hsGPA, and total SAT score
*indicates a p-value of less than 0.05

Table 7. Multiple regression coefficients for Research Question 1

		Intercept	DCT	GPA	SAT
CNSVS Standard Score					
Verbal Memory	B	116.21	-1.02	-2.58	0.002
	t(p)	4.57 (<0.001)*	-1.40 (0.166)	-0.30 (0.764)	0.15 (0.881)
Visual Memory	B	87.38	-0.53	5.16	<0.001
	t(p)	4.12 (<0.001)*	-0.87 (0.388)	0.72 (0.473)	-0.01 (0.993)
Psychomotor Speed	B	101.76	-0.12	5.63	-0.01
	t(p)	6.71(0.001)*	-0.28 (0.780)	1.12 (0.226)	-1.34 (0.184)
Reaction Time	B	96.53	0.21	1.12	-0.001
	t(p)	5.12 (<0.001)*	0.41 (0.685)	0.18 (0.859)	-0.12 (0.902)
Complex Attention	B	60.94	-1.14	-10.13	0.05
	t(p)	1.34 (0.184)	-0.87 (0.384)	-0.66 (0.511)	**2.48 (0.015)***
Cognitive Flexibility	B	84.28	-0.47	2.84	0.01
	t(p)	4.49 (<0.001)*	-0.87 (0.385)	0.45 (0.655)	0.72 (0.474)
Processing Speed	B	54.28	-0.32	13.04	0.004
	t(p)	2.81 (0.006)*	-0.58 (0.565)	**2.00 (0.049)***	0.463 (0.644)
Executive Functioning	B	82.92	-0.37	3.21	0.01
	t(p)	4.65 (<0.001)*	-0.71 (0.478)	0.53 (0.596)	0.70 (0.486)
Reasoning	B	98.63	0.19	-9.47	0.02
	t(p)	5.34 (<0.001)*	0.35 (0.731)	-1.46 (0.148)	**2.31 (0.023)***
Sensory Organization Test					
Composite Score	B	72.52	0.09	-6.81	0.02
	t(p)	8.21 (<0.001)*	0.35 (0.726)	**-2.34 (0.022)***	**4.30 (<0.001)***
Condition 3 Change Score	B	1.18	-0.16	-0.11	0.19
	t(p)	0.13 (0.900)	-1.41 (0.164)	-0.75 (0.457)	1.27 (0.207)
Condition 4 Change Score	B	28.48	0.04	-0.10	0.01
	t(p)	0.99 (0.328)	0.31 (0.756)	-0.64 (0.527)	0.06 (0.955)
Condition 5 Change Score	B	0.83	-0.03	0.13	-013
	t(p)	0.04 (0.971)	-0.23 (0.821)	0.84 (0.404)	-0.81 (0.418)
Condition 6 Change Score	B	3.33	-0.09	-0.04	0.14
	t(p)	0.12 (0.902)	-0.78 (0.438)	-0.24 (0.814)	0.891 (0.376)

*indicates a p-value of less than 0.05

Table 8. Statistical results for Research Question 2 multiple regression models

	F Value †	p	R^2
CNSVS Standard Score			
Verbal Memory	0.61	0.611	0.05
Visual Memory	0.52	0.674	0.05
Psychomotor Speed	0.52	0.674	0.05
Reaction Time	1.08	0.376	0.12
Complex Attention	0.34	0.799	0.03
Cognitive Flexibility	0.42	0.738	0.04
Processing Speed	0.85	0.475	0.07
Executive Functioning	0.71	0.554	0.06
Reasoning	1.04	0.390	0.10
Sensory Organization Test			
Composite Score	0.02	0.997	<0.01

† All regression models had 3 degrees of freedom, Predictor variables were average motivation index score, unweighted hsGPA, and total SAT score

Table 9. Multiple regression coefficients for Research Question 2

		Intercept	DCT Average	GPA	SAT
CNSVS Standard Score Change Score					
Verbal Memory	B	-35.41	0.001	-5.43	0.03
	t(p)	-0.63 (0.534)	0.001 (0.999)	-0.35 (0.727)	1.28 (0.209)
Visual Memory	B	-13.75	0.855	11.33	-0.02
	t(p)	-0.28 (0.785)	0.53 (0.601)	0.83 (0.415)	-0.95 (0.350)
Psychomotor Speed	B	24.34	-0.98	-5.24	0.006
	t(p)	0.79 (0.436)	-0.98 (0.335)	-0.62 (0.540)	0.48 (0.635)
Reaction Time	B	61.08	0.327	-12.31	-0.01
	t(p)	1.52 (0.140)	0.26 (0.796)	-1.14 (0.265)	-0.61 (0.550)
Complex Attention	B	94.81	-1.57	-22.56	0.004
	t(p)	0.95 (0.352)	-0.51 (0.611)	-0.82 (0.419)	0.11 (0.917)
Cognitive Flexibility	B	18.33	0.34	-2.13	-0.01
	t(p)	0.70 (0.488)	0.40 (0.691)	-0.30 (0.769)	-0.63 (0.532)
Processing Speed	B	48.70	0.31	-19.98	0.02
	t(p)	1.06 (0.295)	0.21 (0.834)	-1.60 (0.121)	0.81 (0.426)
Executive Functioning	B	16.60	0.67	-1.82	-0.01
	t(p)	0.63 (0.531)	0.79 (0.434)	-0.25 (0.802)	-0.74 (0.464)
Reasoning	B	84.94	-0.60	-14.58	-0.01
	t(p)	1.85 (0.075)	-0.40 (0.692)	-1.01 (0.283)	-0.54 (0.592)
Sensory Organization Test Change Score					
Composite Score	B	8.48	-0.04	-0.99	0.001
	t(p)	0.47 (0.644)	-0.06 (0.951)	-0.21 (0.833)	0.13 (0.900)

Table 10. Pearson Correlation Values for Change Score to Average Motivation Index

	n	R	p
CNSVS Standard Score			
Verbal Memory	50	0.081	0.575
Visual Memory	50	0.085	0.555
Psychomotor Speed	50	-0.071	0.625
Reaction Time	43	0.106	0.498
Complex Attention	49	-0.036	0.805
Cognitive Flexibility	51	0.253	0.073
Processing Speed	51	0.097	0.500
Executive Functioning	**52**	**0.279**	**0.045***
Reasoning	46	-0.052	0.730
Sensory Organization Test			
Composite Score	50	0.005	0.972

*indicates a p-value of less than 0.05

CHAPTER 5

DISCUSSION

The primary purpose of this study was to determine if academic profile information and motivation test scores would predict baseline and re-test changes in neurocognition and postural control. The secondary purpose of this study was to understand the relationship between motivation and practice effects on neurocognitive and postural control assessments. The most important finding observed was that some of variance in baseline measures of cognitive flexibility, processing speed, and postural control could be explained by baseline motivation index, total Scholastic Assessment Test (SAT) score, and unweighted high school grade point average (hsGPA), but in general, this model does not entirely predicted baseline scores or change scores on neurocognition and postural control in a meaningful way.

Baseline Performance

While many test manufacturers provide age-related norms that individual scores can be compared to, this does not take into account many individual characteristics that can affect neurocognitive or postural control performance. Our results suggest that sports medicine professionals should take motivation, hsGPA, and total SAT scores into account when interpreting the validity of processing speed, complex attention and the composite score of the Sensory Organization Test (SOT). Ideally a clinician would be able to compute an athlete's expected baseline score based on their reported academic profile and measured level of motivation. This would allow clinicians that do not have the resources to complete baseline testing to bypass the lengthy and expensive process of establishing individualized measures on each athlete. Predicting these scores would also allow clinicians to compute an expected score when an athlete lacks neurocognitive and postural control baseline scores. However, our model does not explain enough of the variance in these scores to be able to accurately estimate an athlete's baseline performance. This suggests that other factors, that were not included in this model, such as influential factors such as intelligence quotient (IQ), current life stresses, or quality and quantity of sleep, and the number of individuals tested at a time may also influence neurocognitive and postural control performance (Manly, Jacobs et al. 2002; Doyle, Wozniak et al. 2009; Goel, Rao et al. 2009; Kontos, Elbin et al. 2010; Moser, Schatz et al. 2011). Neurocognitive and postural control measures reflect an athlete's state at the time of the testing. Life events that precede baseline concussion, like a death in the family or intense academic demands, cannot be controlled and may negatively affect neurocognitive and postural control performance.

Although our model did not explain a large percentage of the variance, we suggest that sports medicine professional at least consider baseline motivation and academic profile when assessing the validity of baseline measures as they do still explain some of the variance (Bailey, Echemendia et al. 2006; Hunt, Ferrara et al. 2007). Sports medicine professionals that utilize invalid baseline clinical concussion measures may prematurely return an athlete to play before they have fully recovered from their concussion. This may put athletes at risk of negative postconcussive outcomes, such as second impact syndrome (Cantu 1998; Cantu and Gean 2010). It was surprising to the investigators that these variables were not significant predictors for more of the neurocognitive domains as both motivation and the academic profile has been shown to have a relationship with neurocognitive performance (Echemendia, Putukian et al. 2001; Manly, Jacobs et al. 2002; Bailey, Echemendia et al. 2006; Hunt, Ferrara et al. 2007).

Motivation Index Score

Motivation was not a significant predictor of baseline test performance on any of the neurocognitive and postural control outcome measures. This could be due in part to the nature of the scoring. Many of the studies that use the Dot Counting Test to measure motivation use specific cut off scores to create groups (high and low motivation) (Boone, Lu et al. 2002; Hunt, Ferrara et al. 2007). The use of motivation as a continuous variable may have been an incorrect assumption, therefore it can be theorized that motivation may be an "all-or-nothing" component of clinical concussion measures. As a part of the multivariate regression analyses we employed for research question 1, a correlation was run between the different predictor and criterion variables. Interesting to note was a positive relationship between the baseline motivation index scores and the reasoning standard score and reaction time standard score. This suggests that as motivation decreases (higher scores indicate lower motivation), the performance on some neurocognitive and postural control measures improves though these findings were not significant.

These results contradict previous studies that suggest that increases in motivation should result in increases in neurocognitive and postural control performance (Bailey, Echemendia et al. 2006; Hunt, Ferrara et al. 2007). However, there were many differences between these studies and ours. Hunt and colleagues (Hunt, Ferrara et al. 2007) used the same Dot Counting Test, but compared concussion outcomes measures between a high and low motivation group among high school athletes. Bailey and colleagues (Bailey, Echemendia et al. 2006) did not use a separate motivation test, athletes that extended high and low effort were identified based on their performance on the baseline neurocognitive measures. The results from these researchers suggest that motivation may be a dichotomous variable rather than continuous.

High School Grade Point Average

High School GPA was a significant predictor of the processing speed standard score and the SOT composite score. This domain is computed from the Finger Tapping Test and the Symbol Digit Coding Test and attempts to measure the speed and accuracy of simple learned tasks. Previous studies indicate a positive relationship between visuospatial working memory and scholastic testing in a younger population (St Clair-Thompson and Gathercole 2006). This relationship between visuospatial working memory and scholastic testing could explain the predictive relationships that we observed in this study (St Clair-Thompson and Gathercole 2006). When assessing baseline scores for validity, clinicians should expect athletes with higher high school GPAs to have higher scores in domains related to visuospatial working memory.

We suspect that we may not have observed hsGPA as a significant predictor because of the lack of precision in the measures. The high school GPA values reported to us by the admission office varied between one and three decimal places. Because of the variety of precision, we may not have been able to identify subtle differences between athletes' academic capabilities. Also, the sample used was fairly homogenous and did not provide a wide variety of both hsGPA and total SAT scores. Future studies should consider using other measures of academic performance, such as collegiate GPA, National Collegiate Athletic Association GPA or the American Collegiate Test, which are also widely available in a student-athlete population.

Scholastic Assessment Test

Total SAT score was a significant predictor of the complex attention standard score, reasoning standard score, and SOT composite score. This could be due to the fact that like the SAT, baseline clinical concussion measures are a cross-sectional measure. Specifically, we suspect that there are inherent similarities between the mode of administrations of our neurocognitive test battery and the SAT because both are completed on a computer. The scale that the SAT uses may be better suited than hsGPA in identifying subtle academic differences between individuals. The Stroop and continuous performance subtests are used to compute the complex attention domain score require the same visuospatial working memory, which have previously been reported to share a relationship with academic profile (St Clair-Thompson and Gathercole 2006). Because the reasoning domain standard score is comprised of one version of the Non-Verbal Reasoning Test, test-wiseness could account for SAT's predictive ability of this domain.

Our results support our hypothesis that the attribute of test-wiseness, often described in academic and educational literature for cognitive/academic tasks, could also be transferred to neurocognitive and postural control tasks typically used during baseline and post-concussion assessment (Whalstrom and Boersma 1968; Sarnacki 1979). For example, the SOT utilizes "sway referencing" where the surround and platform move in reference to the movement of the athletes' center of pressure during certain conditions. It seems possible, that athletes with good test-wiseness may more easily become wise to the fact that their sway influences the movement of the platform and surround as they progress through the repetitions of the same conditions multiple times in a single test sessions. It seems possible that athletes that have higher scholastic aptitude as measured by the SAT would be better able at developing strategies for controlling posture during the SOT. This also suggests that individuals with higher academic profiles are better able to adapt, identify, and ignore the incorrect sensory information better than individuals with lower academic profiles. However these results appear to only be true for overall postural control and sensory organization performance, but not for acute practice effects observed between trials one and three for conditions that involve sway-referencing. This supports previous research concluding that the individual trials from a single test session are not reliable. Our results also suggest that academic profile and motivation cannot account for any of the variance between the individual trials (Dickin and Clark 2007; Dickin 2010). This also suggests that academic profile and motivation have no interaction the individual systems.

Practice Effect between Baseline and Re-Test Session

We hypothesized that there would be a strong predictive relationship between motivation and academic profile and the practice effects in the verbal memory, visual memory, complex attention, cognitive flexibility, executive functioning and reasoning domains as well as the SOT composite score. However, our model did not significantly predict practice effects in any of our outcome measures. Also, there was not a significant difference between the baseline group and re-test group with respect to the hsGPA ($t=1.66$, $p=0.11$and baseline motivation index scores ($t=-0.30$, $p=0.77$). There was however a difference between the baseline group and re-test group in SAT scores ($t=2.12$, $p=0.41$) These results differ from Miller et al. where the authors observed an interaction effect between SAT and collegiate GPA on the test re-test reliability of a computerized neurocognitive testing (Miller, Adamson et al. 2007). However this study had a larger sample size at baseline and re-test ($n=68$) than our study. We conclude that results that we observed are likely due to our small sample size.

These analyses had maximum of 36 participants. We observed a low follow-up reporting rate from the participants who we had complete academic profile information. We suggest that future studies seek to address to possible predictive nature of motivation and academic profile, by utilizing a larger sample size. In part, our small sample size was attributable to a lack of availability of hsGPA in the athletes that reported for the second session of testing. This caused us to seek out self-reported hsGPA. We were encouraged to find that athletes could reliably report their hsGPA and SAT scores. Including a self-reported hsGPA and SAT score as part of a demographic form that each athlete fills out at baseline may supplement a clinicians ability to interpret neurocognitive and postural control. Future studies should consider using a larger sample size that represents athletes from universities or high schools with varying levels of academic rigor in order to obtain more heterogeneous set of hsGPA and SAT scores.

Relationship between Motivation Index and Change Scores

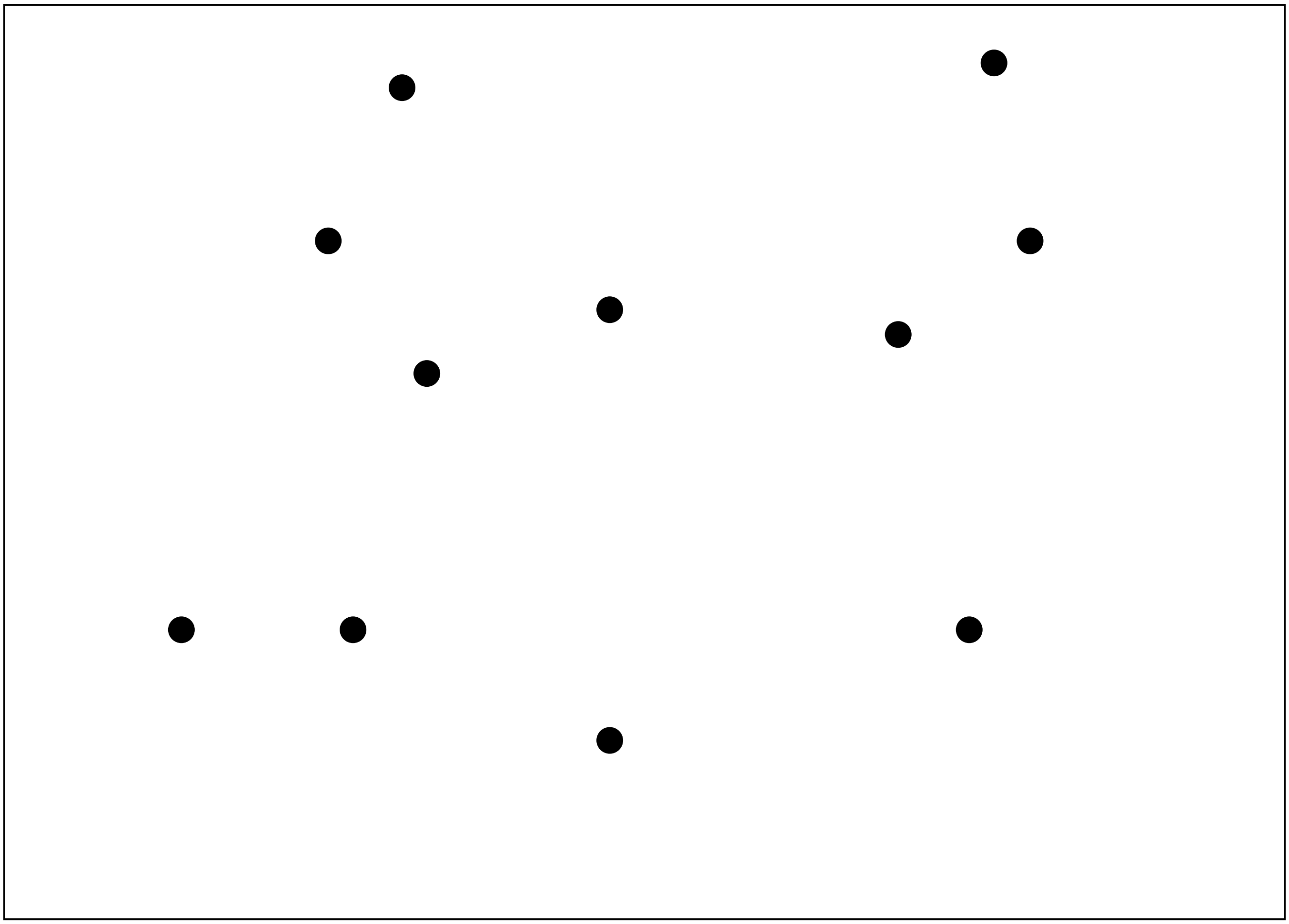
We hypothesized that there would be a negative relationship between average motivation index scores and the change scores computed for each outcome measure. We observed a low positive relationship between executive functioning and the average motivation index score. These results suggest that, to some extent, athlete's with low average motivation (having a higher motivation index score) present with larger practice effects in executive functioning. Although not significant, only three of the domains showed a negative relationship: psychomotor speed, complex attention, and reasoning . The standard deviations of the change scores of the standard scores for each domain suggests that not all individuals improved at re-test and showing that there was not a consistent relationship between the neurocognitive standard scores and the average motivation index scores. Furthermore, the means of the baseline motivation and the re-test motivation were very similar which suggest that there was no practice effect for the Dot Counting Test between the two test sessions.

Conclusion

The results of this study suggest that motivation and academic profile alone do not predict a meaningful amount of the variance in baseline clinical concussion measures. Further research is necessary to identify other factors that might help clinicians better assess the validity of an athletes' neurocognitive and postural control measures relative to their individual capabilities. While some of the models yielded significant results, predictive strength of the variables examined are insufficient to recommend replacing baseline testing. However, we suggest that clinicians continue to consider motivation and academic profile when interpreting baseline and post-concussion measures in the clinical decision making process as some of the variance was explained with these variables. The major limitation of this study was a small sample size for the re-test analyses. We suggest that future research investigating motivation and clinical concussion measures consider using previous published cut-offs for motivation index scores to identify athletes that either do or do not extend effort (Boone, Lu et al. 2002). Furthermore, this research shows that there are other influential factors such as intelligence quotient (IQ) or personal perceived risk of sustaining a concussion that affect baseline test performance that have yet to be examined. Further research needs to be done in order to understand the factors that affect neurocognitive and postural control measures to strengthen predictive model.

Appendix A: Dot Counting Test

Ungrouped



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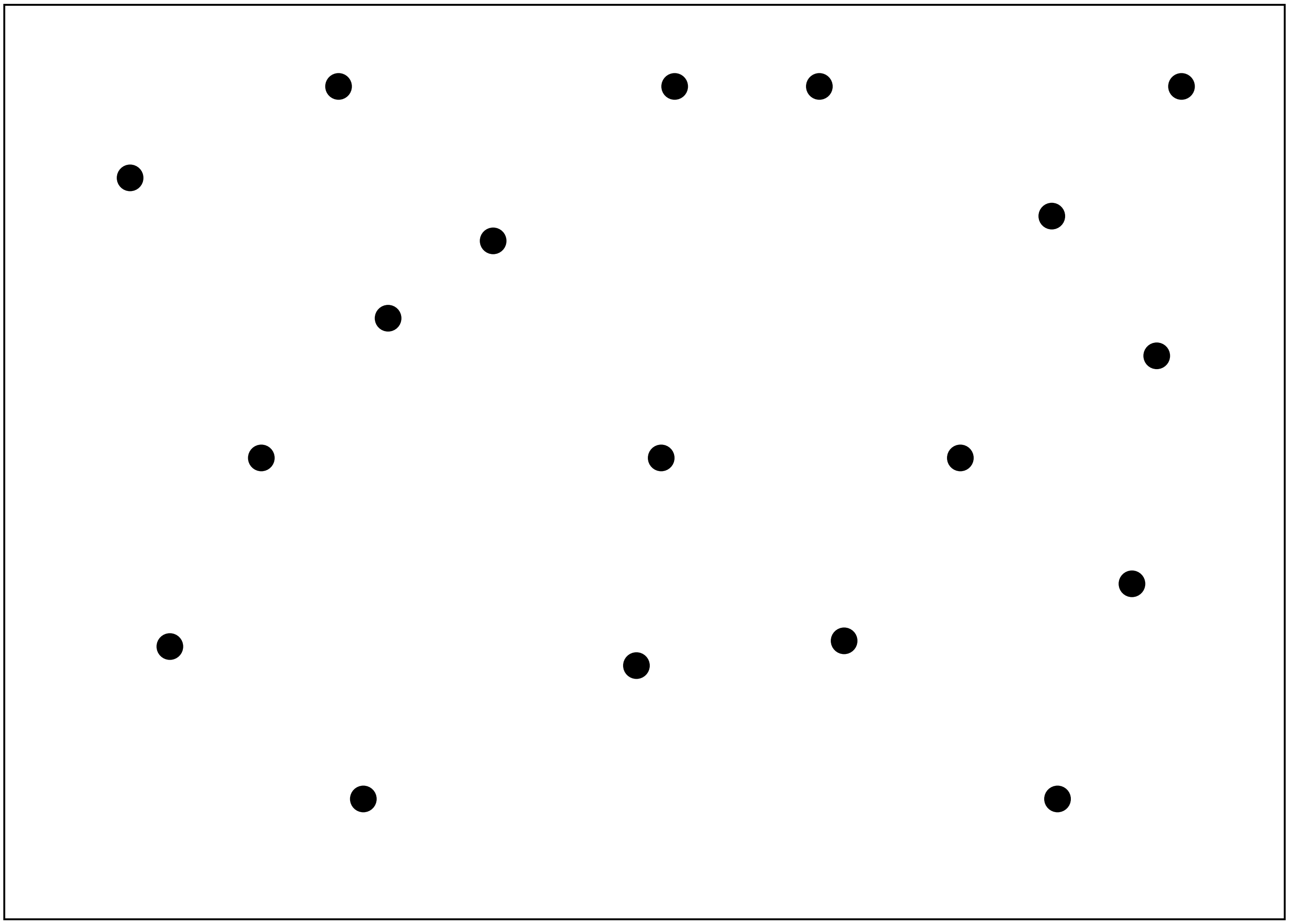

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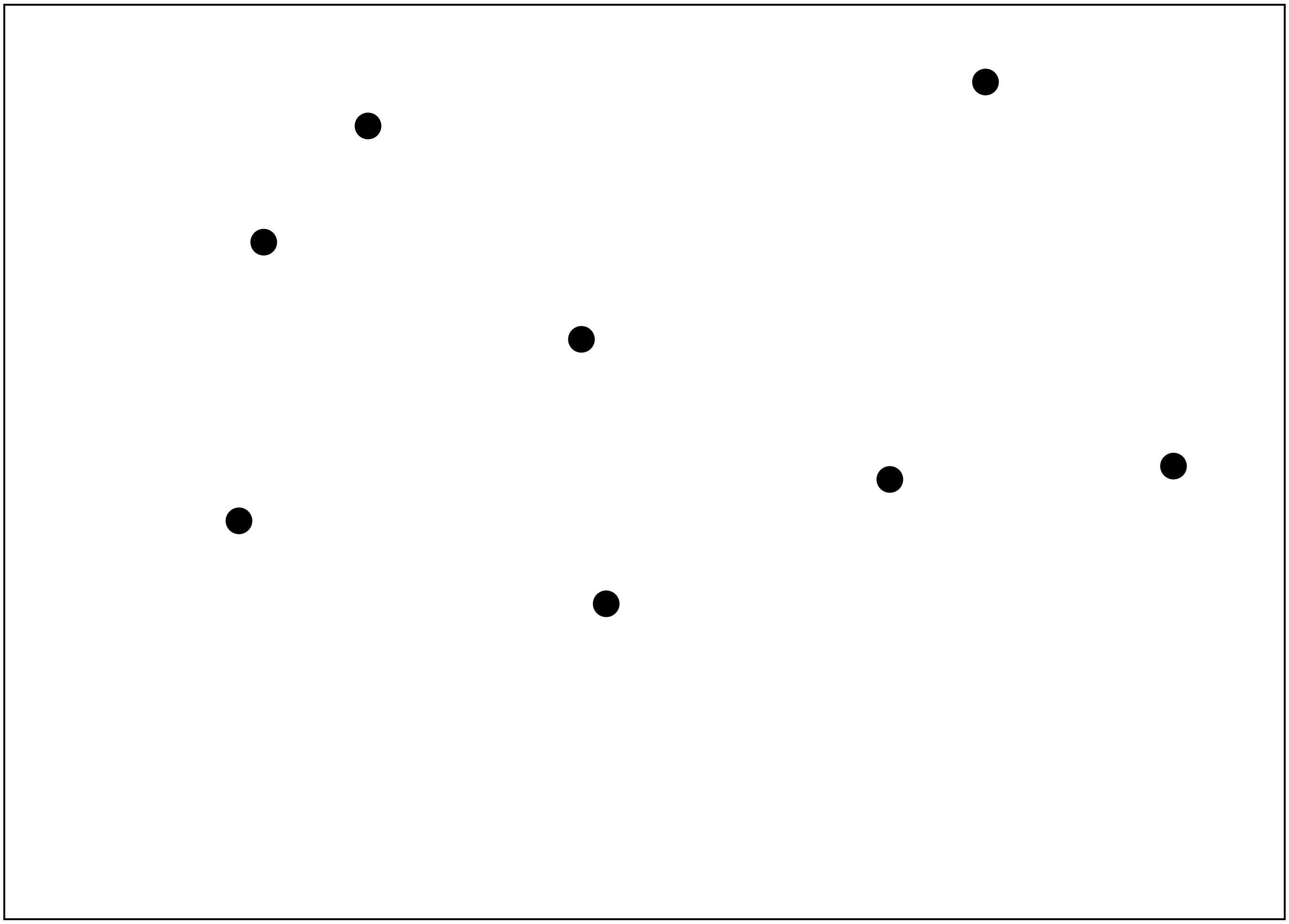

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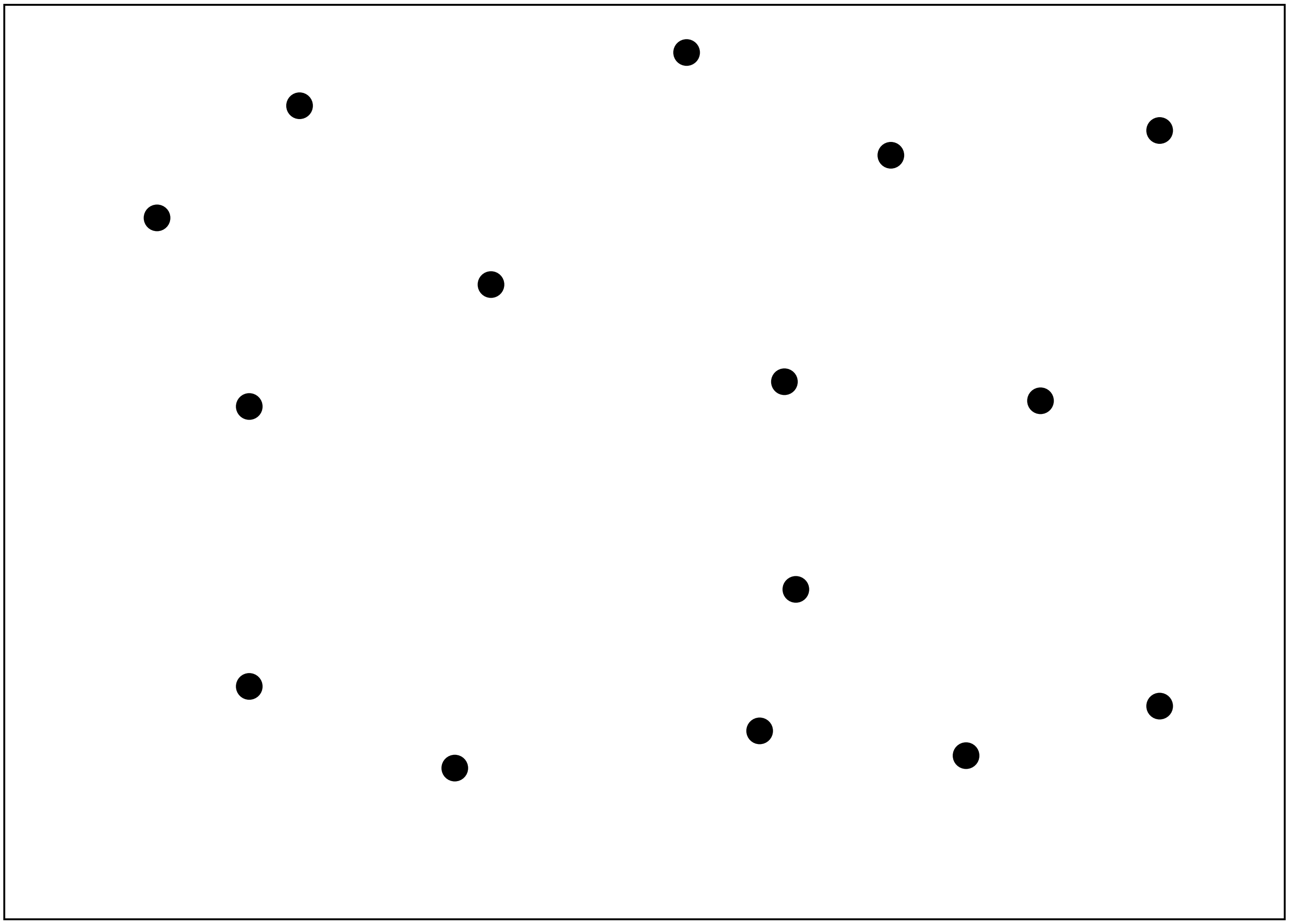

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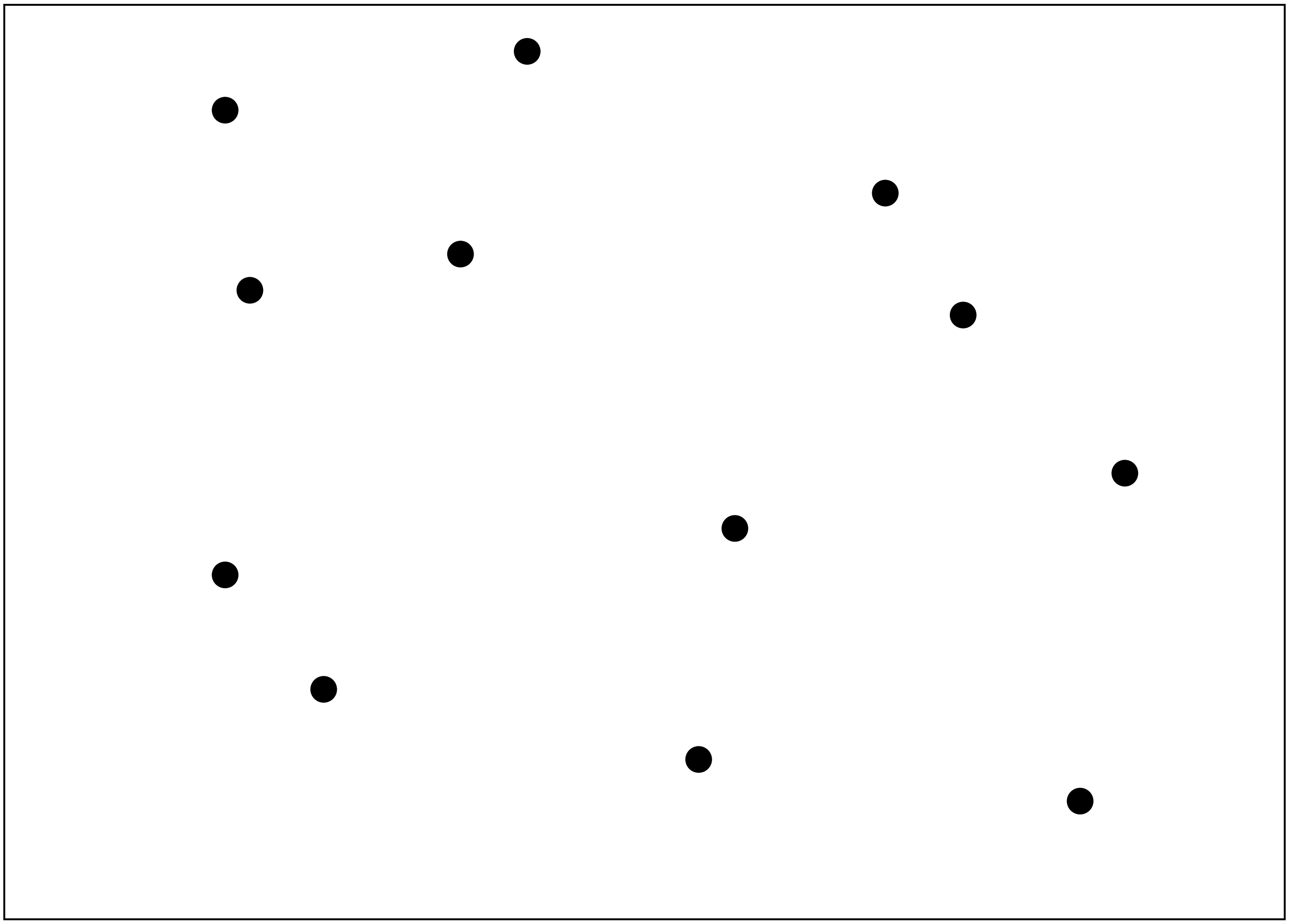

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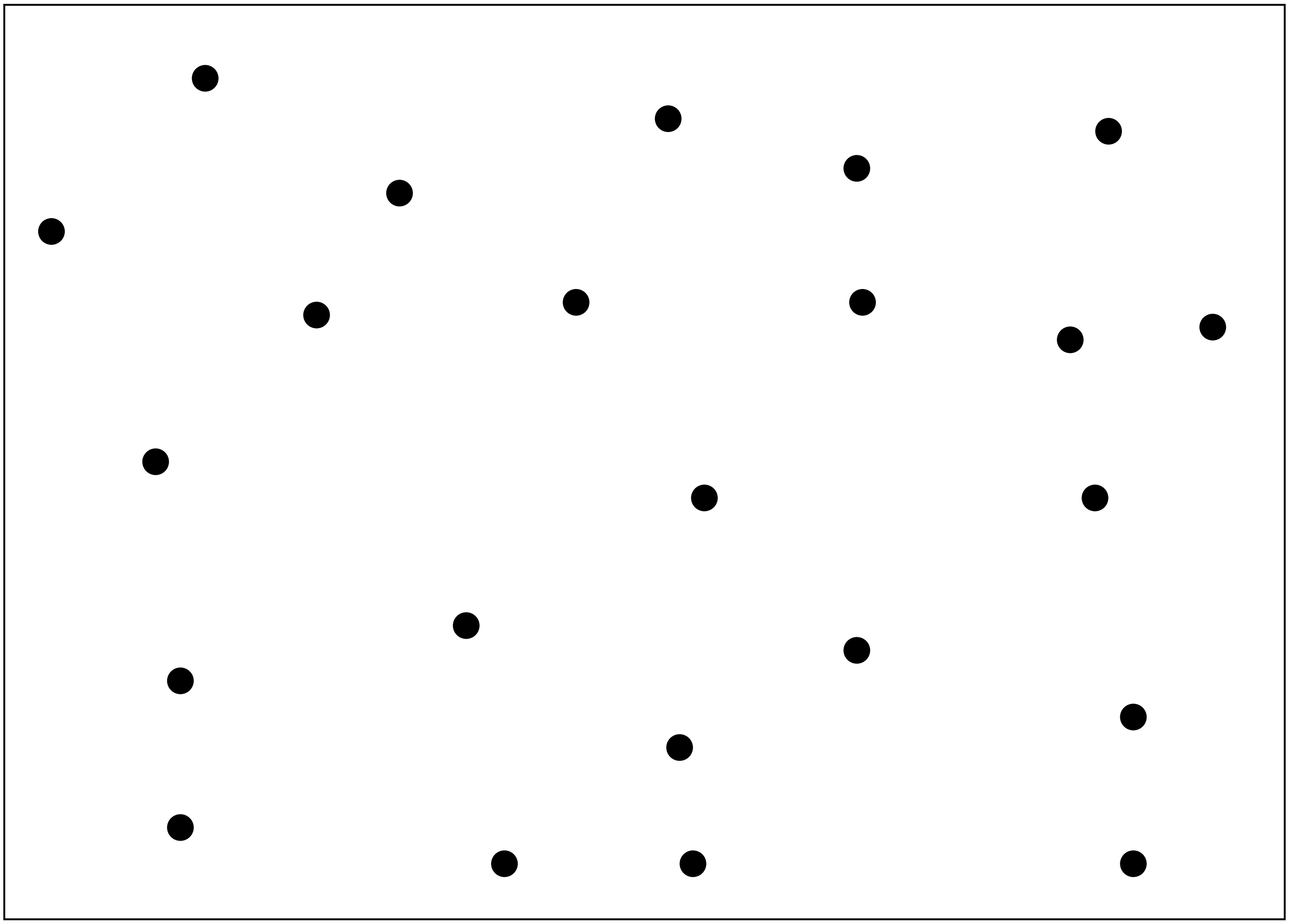

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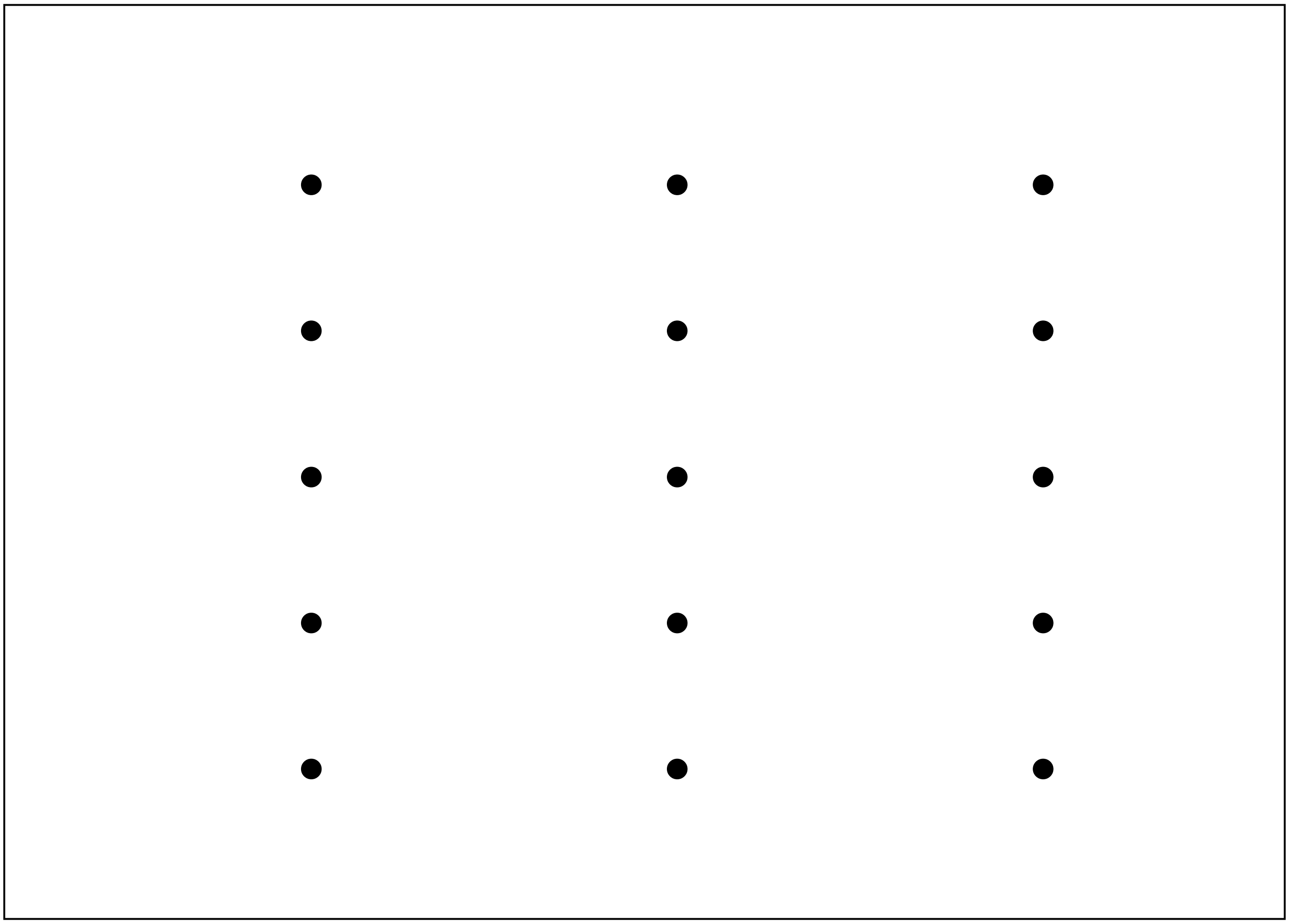
Grouped



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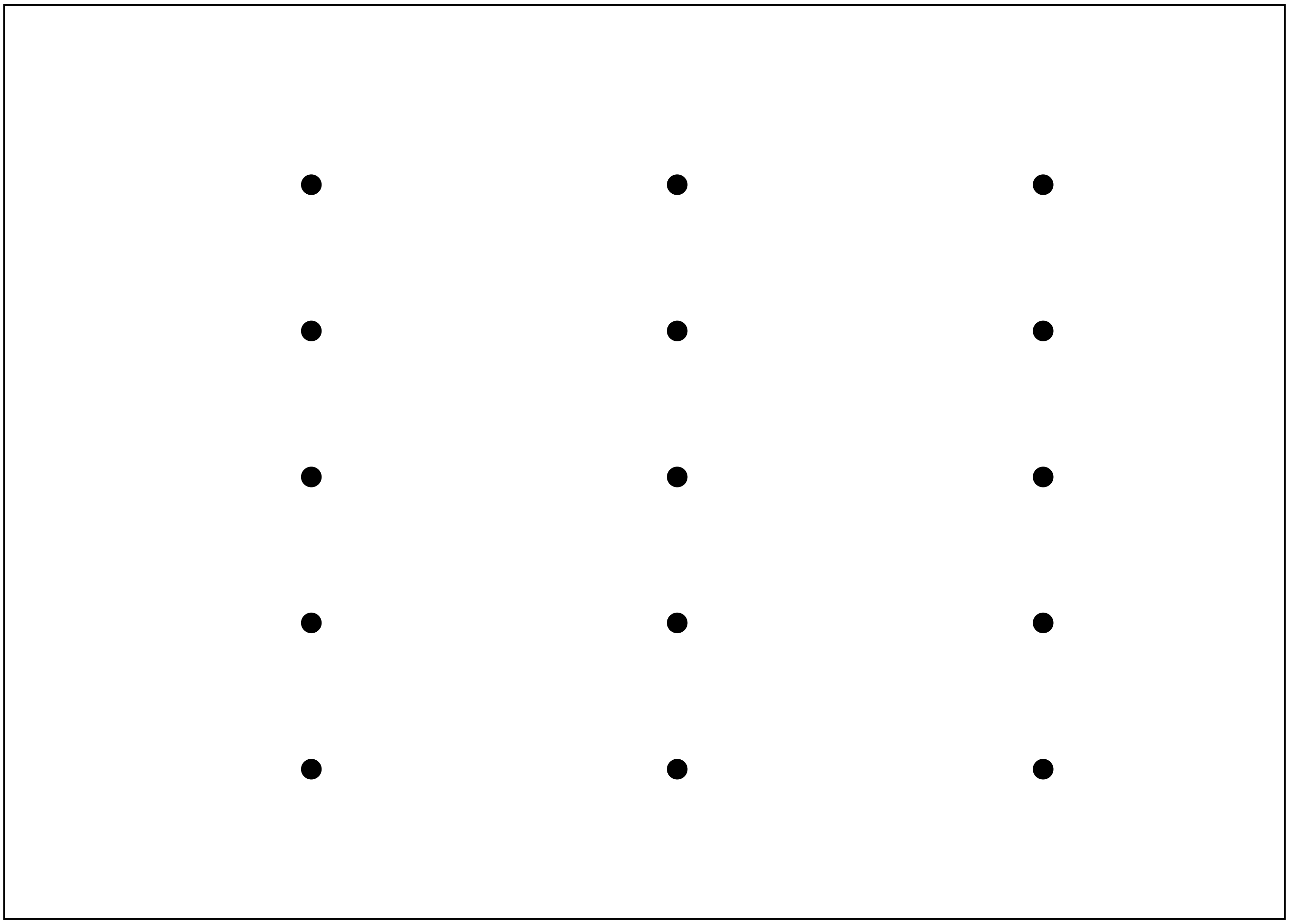

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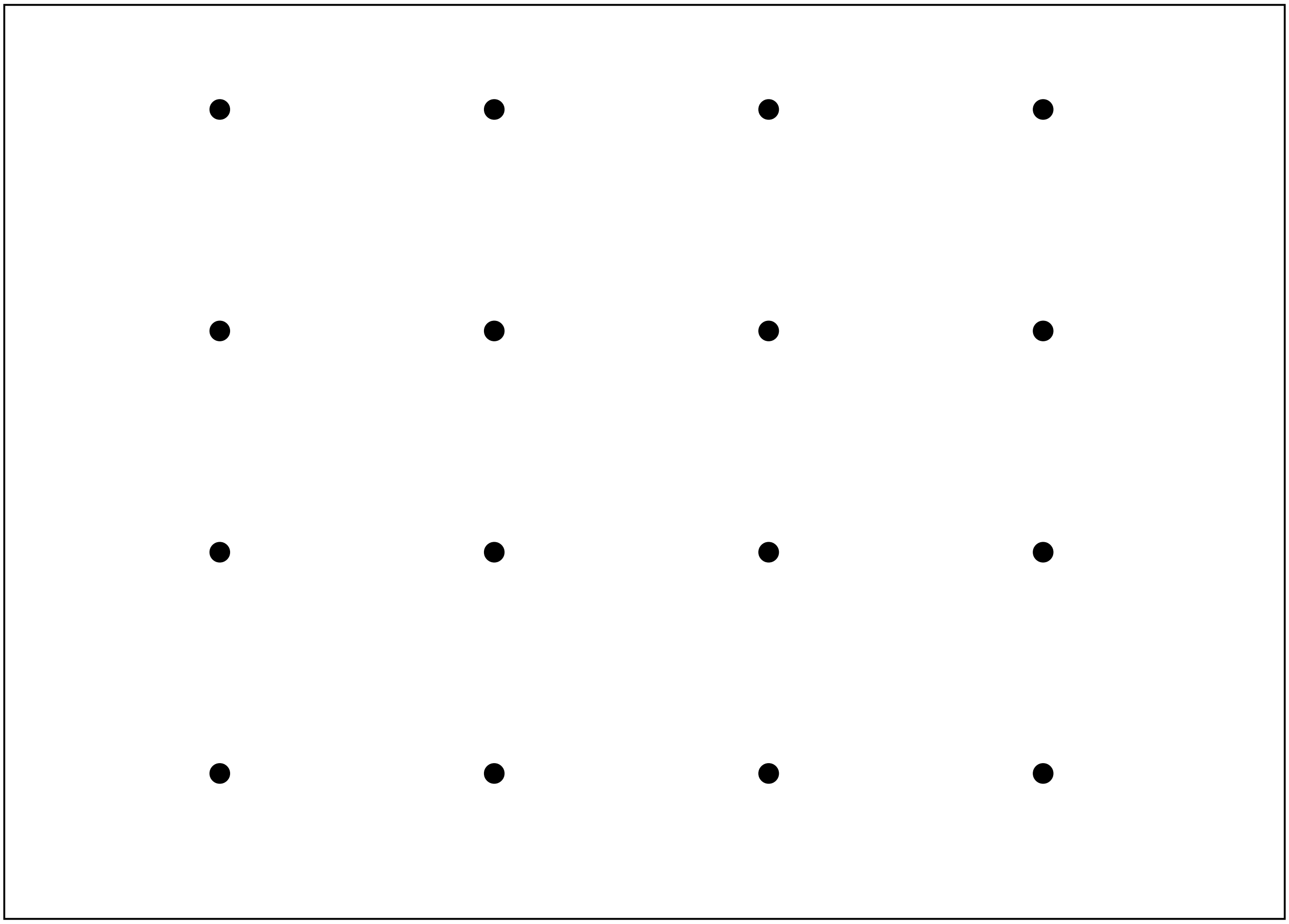

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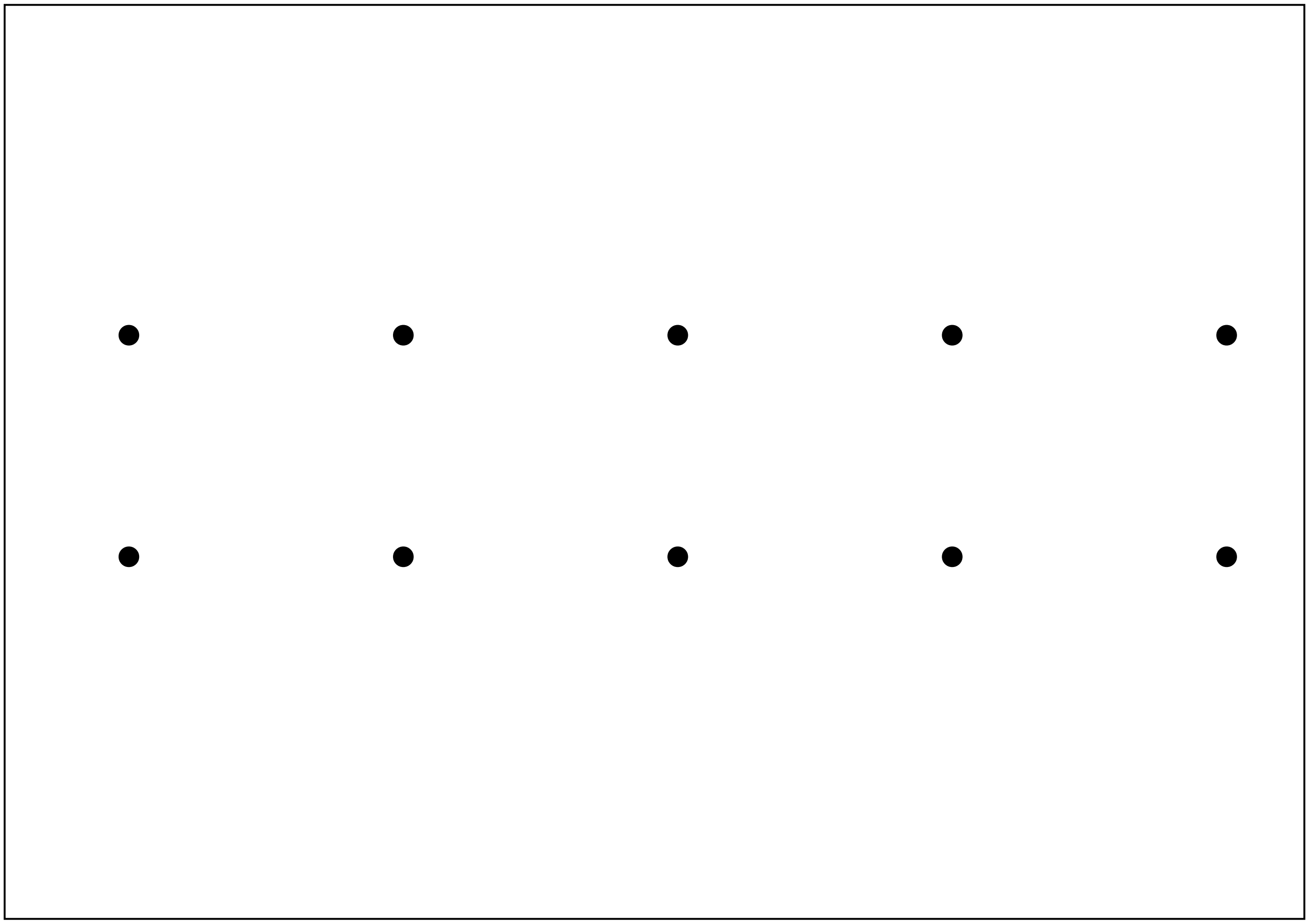

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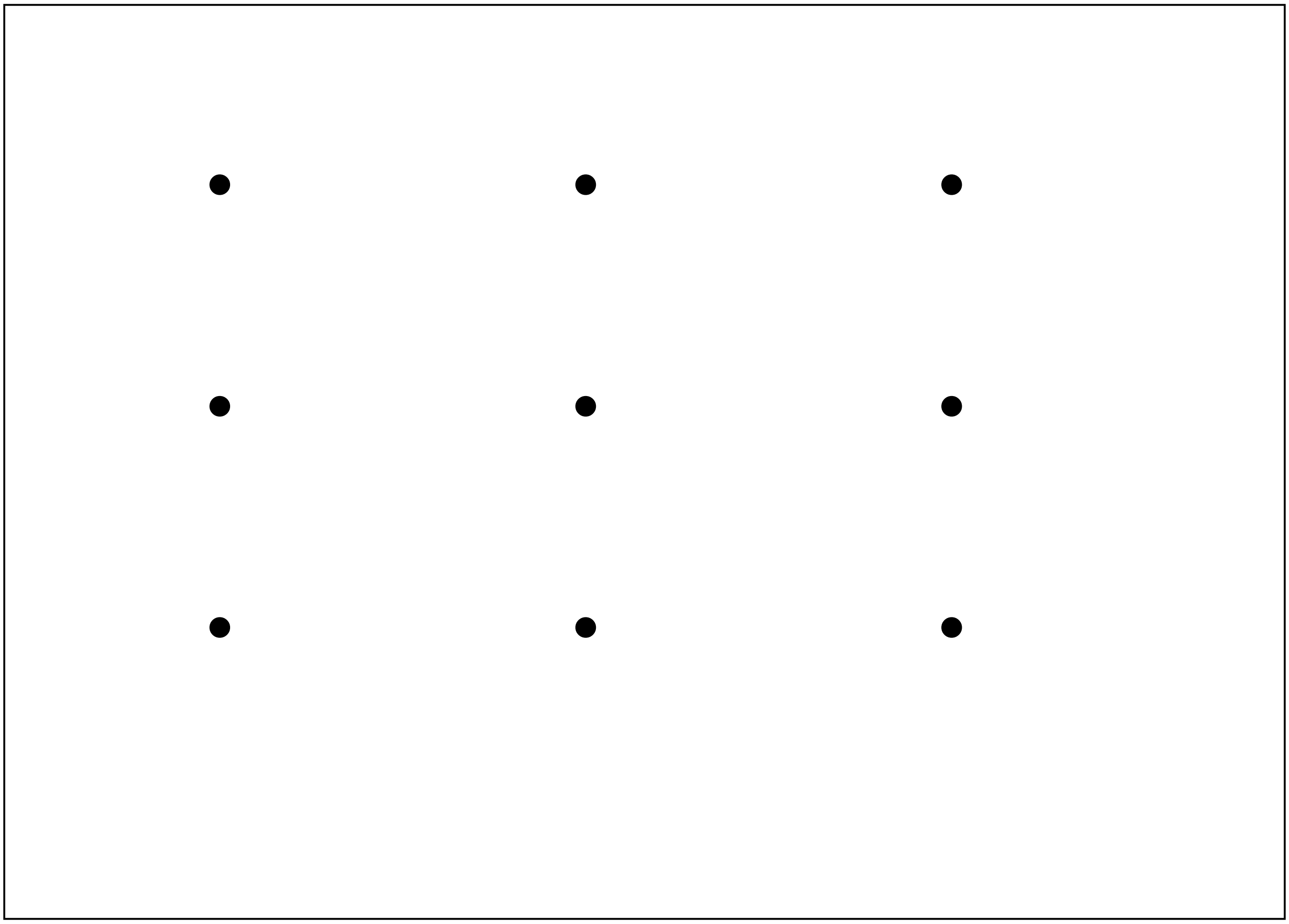

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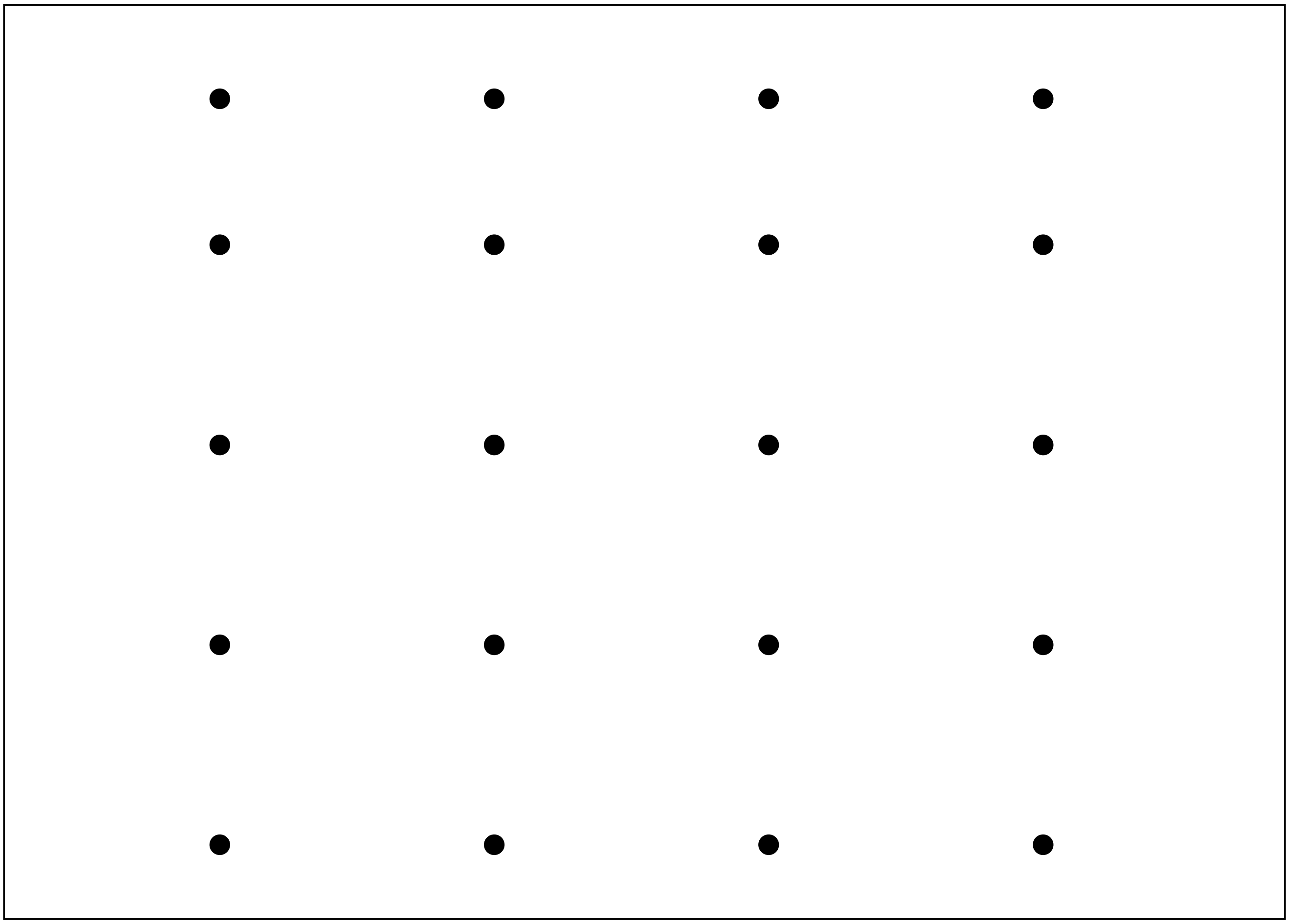

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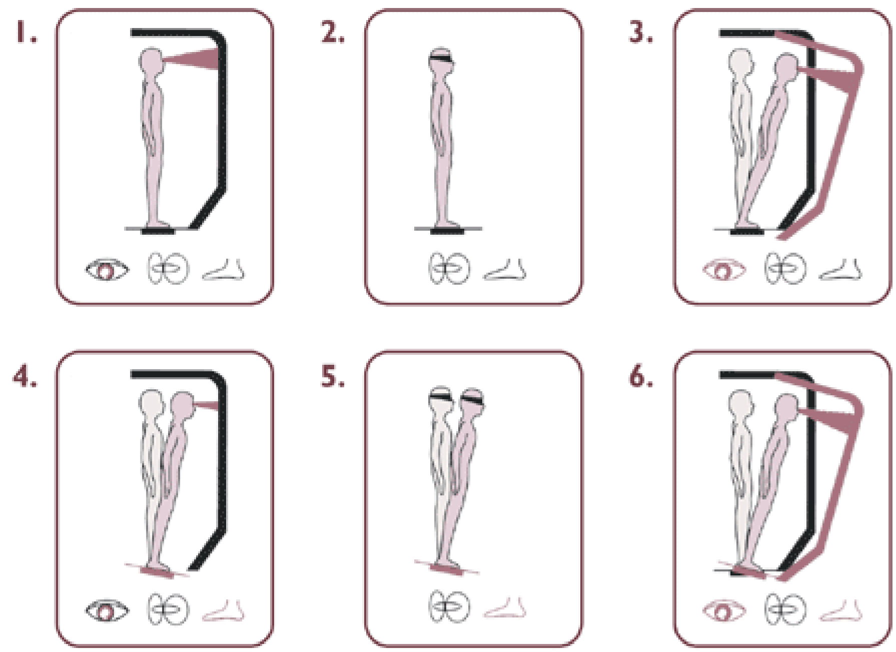
Appendix B: Graded Symptom Checklist

Postconcussion Symptom Scale (PCSS)							
Circle appropriate number for each symptom experienced on a regular basis (> 3 times/wk)							
Symptom	None	Mild		Moderate			Severe
Headache	0	1	2	3	4	5	6
Nausea	0	1	2	3	4	5	6
Vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Poor balance	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Ringing in the ear	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Feeling mentally "foggy"	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Fatigue	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Neck pain	0	1	2	3	4	5	6

Appendix C: Conditions of The Sensory Organization Test



Sensory Organization Test

APPENDIX D: Demographic Questionnaire

Last Name:__________________________ First Name:______________________

Middle Initial:______

Height: ____ ft ____ in

Weight: _____ lbs

Setting: College ___ High School ____ Elite ____ Other: ____________________

Academic Year: __ Freshman __ Sophomore ___ Junior ___ Senior

Eligibility Year: ____

Race: ___ African American ____ Asian ___ Caucasian (White) ___ Hispanic

___ Native American ___ Other ____________

Handedness: ___ Right ____ Left ___ Both

Gender: ___ Male ___ Female

Native Language: _________________

Secondary Language: __________________ How long?___________

Years of Education: _______________________ SAT Total**:** ___________ of _____

Have you ever received speech therapy? __________

Have you ever attended special education classes? ___________

Have you ever repeated one or more years of school? _____________

Have you ever been diagnosed with attention deficit disorder (ADD) or attention deficit disorder with hyperactivity (ADHD)? ___________

Have you ever been diagnosed with a learning disability? ___________

Have you ever had a concussion? ____ if so how many? ____

Approximate date of injury? ________

Days lost ____ Was it sport related? ___________ Did you lose consciousness? ____

Did the concussion result in confusion? ____

Did the concussion result in a difficulty remembering events immediately before? ____

Did the concussion result in a difficulty remembering events immediately after? ____

Indicate whether you have experienced the following:

Treatment for headache by a physician? _________

Treatment for migraine headache by a physician? __________

Treatment for epilepsy/seizure? __________

Treatment of brain surgery? ___________

History of meningitis? __________

Treatment for substance/alcohol abuse? ___________

Psychiatric conditions? ____________

APPENDIX E: Manuscript

Predicting Baseline Clinical Concussion Measures Based on Academic Profile and Motivation

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Running Title: Predicting Baseline Concussion Measures

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Paragraph Number 1

Introduction

Concussion evaluation involves a multifaceted approach that includes a thorough clinical evaluation, that includes measures of neurocognition, postural control, symptom severity, along with a clinical evaluation [1]. Recently, the NCAA mandated that all member institutions must have a concussion policy on file and require that athletes of all sports are made aware of the possibilities of sport-related concussions [2]. The purpose of baseline testing is to aid medical professionals in identifying post-injury declines in neurocognitive and postural control performance in order to guide safe return to play decisions. The value of baseline neurocogntive and postural control measures has recently come into question because of the numerous factors that influence these scores [3].

Paragraph Number 2

Previous studies suggest that student-athletes that perform poorly on motivation testing also perform poorly on the clinical concussion measures [8, 9]. Many athletes are disinterested in the test battery and do not exert their full effort [8]. This leaves many sports medicine professionals with the problem of invalid baseline scores that do not provide a true representation of the athlete's capabilities. Invalid baseline scores that go unrecognized could cause sports medicine professionals to make premature decisions to allow the athlete to return to play before they have recovered from their concussion. Also, it has been reported that approximately half of sports medicine professionals that administer baseline computerized neurocognitive testing, check for the validity of the baseline scores [10]. Athletes that return to play prematurely are at risk of sustaining a second, seemingly innocuous, impact to the head or body that could result in death or permanent brain damage [11].

Paragraph Number 3

Individuals that are academically successful have also been found to be better test takers [4, 5]. In the education community this is called test-wiseness. Miller *et al.*[6] found that both Scholastic Aptitude Test (SAT) score and collegiate Grade Point Average (GPA) influence test-re-test reliability of a neurocognitive test batteries. Athletes that are more test-wise may have an enhanced ability to inflate their performance on neurocognitive and postural control measures when they repeat these measures following concussion. Following concussion, test-wise athletes may appear to be recovered, when in fact they still have lingering neurocognitive or postural control deficits. Considering recent recommendations that suggest serial assessment during the recovery process of a sport-related concussion, it is important to understand how test-wiseness affects the results of each test session [7]. However, the extent to which test-wiseness influences baseline concussion measures remains unknown.

Paragraph Number 4

No previous studies have examined the effects of both motivation and academic profile on baseline neurocognitive and postural control performance. The purpose of this study is to determine if motivation index scores, SAT scores, and high school GPA (hsGPA) can predict clinical concussion measures at baseline.

Paragraph Number 5

Methods

Subjects

A total of 165 individuals were evaluated as a part of an ongoing clinical baseline-testing program for all incoming freshman and transfer student-athletes. Ninety-four participants voluntarily provided permission for the research team to access to their academic profile information and met our inclusion and exclusion criteria. Of the ninety-four athletes with complete academic profile information, eight individuals were excluded because they reported one or more of the following criteria: self-reported history of attention deficit disorders, three or more previous concussions, and history of learning disability. We retained a total of eighty-six participants with SAT scores and hsGPA.

Paragraph Number 6

Procedures

Participants reported to the baseline testing session and signed a written informed consent form approved by the university's Institutional Review Board. Participants were told that the purpose of baseline testing was to collect neurocognitive, postural control, and symptom scores from them prior to their season of play so that if they were to sustain a concussion, sports medicine professionals would be able to compare back to these scores that represent their pre-injured state. Each participant was then assigned randomly to a counterbalanced test order including the SOT Test (Neurocom International, Inc., Clackamas, OR), CNS Vital Signs neurocognitive test battery (CNS Vital Signs, Chapel Hill, NC), and graded symptoms checklist. Motivation testing (Rey's Dot Counting Test) occurred at the end of every participant's testing session, as this is when the investigators believed that motivation would be at its lowest point. Participants were told that motivation testing is a paper and pencil neurocognitive test in order to blind them from our intention to measure their motivation as this may affect the amount of effort given. Participants completed baseline neurocognitive testing in a room with no more than three other athletes concurrently testing. Postural control assessments were completed in a room alone with the investigator.

The entire baseline testing session took approximately 60 to 90 minutes for participants to complete. As a part of the informed consent procedures, participant were asked if they were willing to disclose their hsGPA and SAT information to the investigators of the study. Participants had to place a check mark next to “Yes, I do consent” or “No, I do not consent” to disclosing the information. If they left both boxes blank, they were contacted at a later time and asked via e-mail if they consent. If they consented to the disclosure of this information, their names and university personal identification number were collected and sent to the registrar’s and admissions office to obtain their SAT and hsGPA data.

Paragraph Number 7

Instrumentation

All athletes completed a multifaceted baseline clinical concussion assessment including a neurocognitive test battery (CNS Vital Signs), a postural control exam (Sensory Organization Test), and motivation testing (Rey’s dot counting test). The entire baseline testing session took approximately 60 to 90 minutes.

Paragraph Number 8

Neurocogntive Test Battery

The total neurocognitive test battery includes a verbal memory test, visual memory test, finger tapping test, symbol digit coding, stroop test, shifting attention test, continuous performance test, and the non-verbal reasoning test. The entire test battery takes approximately 25 to 30 minutes. Each of the nine subtests is completed as follows:

Paragraph Number 9

i. Verbal Memory Test: The participant was given a set of fifteen words to memorize. The words appear on the screen one at a time for two seconds each. After all fifteen words are shown, a larger list of thirty words is presented on the computer monitor one at a time and the participant was instructed to press the spacebar when a word from the original list is shown on the screen. At the end of the test battery (approximately 20-25 minutes later), the participant was shown a different set of thirty words, which includes the fifteen original words the participant was told to memorize on the monitor. The participant was instructed to press the spacebar when a word that was given in the original list is shown.

Paragraph Number 10

ii. Visual Memory Test: the participant was shown a set of fifteen geometric shapes to memorize, with the symbols being shown one at a time for two seconds each. Thirty geometric shapes was are then shown to the participant one at a time and the participant is instructed to press the spacebar when a symbol from the original list is shown on the screen. At the end of the test battery (approximately 20-25 minutes later), the participant was shown a different set of thirty geometric shapes, which included the fifteen original geometric shapes the participant was told to memorize on the monitor. The participant was instructed to press the spacebar when a geometric shape that was given in the original list is shown.

Paragraph Number 11

iii. Finger Tapping Test: the participant was instructed to use their right index finger to press the spacebar as many times as they can in a ten second period. The participant then does the same thing with their left index finger. The test is scored as an average of the number of taps between the left and right index finger. The participant was given a practice trial for both the left and right index finger before the test is administered.

Paragraph Number 12

iv. Symbol Digit Coding Test: the participant was shown a key in which numbers 2 – 9 are linked to symbols at the top of the screen. Under the key the participant was given a similar key with the symbols in a random order and blank boxes under the symbols. The participant must correctly type in the numbers that are linked to the symbols. The participant has 120 seconds to answer as many blank boxes as possible. The participant was given one practice screen with 8 trials before the test begins.

Paragraph Number 13

v. The Stroop Test: this test is comprised of the words BLUE, RED, YELLOW, and GREEN showing up on the screen against a white background. For the first condition of this test, the participant was instructed to press the spacebar when any word appears on the screen. The text for this condition appears in black. For the second condition, the participant was instructed to press the space bar when the color of the text matches the word on the screen (e.g. the word green written in green font). For the third condition, the participant was instructed to press the spacebar when the color of the text is not the same as the word shown on the screen(e.g. the word green written in blue font). The first condition generates a simple reaction time score based on the time that it took for the participant to press the spacebar. The correct response times from the second and third conditions create the complex reaction score. Typically, the third condition reaction time is greater than the reaction time from the first and second condition. For all scores generated from this test, lower scores are reflective of higher performance on the test.

Paragraph Number 14

vi. Shifting Attention Test: this test utilizes the right and left shift keys on the keyboard. A single geometric shape that is either a circle or a square and colored either red or blue is displayed on the top of the computer screen. The lower portion of the screen displays two additional geometric shapes that are also either a circle or a square and colored either red or blue. Instructions are displayed to either “MATCH COLOR” or “MATCH SHAPE” for that particular test screen. The participant was instructed to press the shift key of the side which matches the condition specified at the top of the screen. The conditions, shapes and colors for all three figures change randomly for ninety seconds. The test collects the number of correct answers given, the number of errors made, and the response time.

Paragraph Number 15

vii. Continuous Performance Test: this test utilizes the spacebar key of the keyboard and a black screen with white text. At the beginning of the test, the participant was instructed to press the spacebar only when the letter “B” appears on the screen. A variety of letters was shown to the participant throughout the test, which lasts roughly five minutes. Over 200 letters appeared on the screen, forty of which are the letter “B” and 160 of which are other letters. Each minute of the test, the letter “B” appeared 8 times. The test collects the number of correct responses, errors of commission and omission.

Paragraph Number 16

viii. Non-Verbal Reasoning Test: this test scored for accuracy and speed and utilizes the number keys 1-5. At the top of the screen was a test grid with two rows and two columns. In the grid there will be one object missing. Below the test grid was the answer grid with 5 columns in a single row numbered 1 through 5. The participant was instructed to press the number key of the object that best fills the blank cell in the test grid. The participant was given two practice trials and then the test was started. The test consists of 15 test grids and the participant was given 14.5 seconds to complete each test grid. The test increases in difficulty as the test goes on. The test was scored by the number of correct responses, the average correct response time, the commission errors, and the omission errors.

Paragraph Number 17

Postural Control Assessment

Student-athletes completed postural control testing using the Sensory Organization Test (SOT) on the SMART Balance Master (NeuroCom International, Clackamas, OR, USA). Shoeless athletes were positioned with a standardized foot placement relative to their height, and instructed to stand with their arms relaxed at their sides, looking straight forward, and standing as still as possible. Center of pressure data were sampled at 100 Hz. The participant stood on two force plates facing forward within a visual surround with their shoes off. The participant then completed three trials of six different sensory conditions. During some conditions the participant’s anterior and posterior sway is “sway referenced”. Sway referencing tilts the force plates anteriorly and posteriorly in order to directly follow the participant’s center of gravity sway, such that the surface of the force plates and the visual surround remain constant in relation to the center of gravity angle. The following are descriptions of each of the six conditions: Condition 1: Participants stood with their eyes open on the fixed force plates with a fixed surround. Condition 2: Participants stood with their eyes closed on fixed force plates with a fixed surround. Condition 3: Participants stood with their eyes open on fixed force plates and sway referenced visual surround. Condition 4: Participants stood with their eyes open on sway referenced force plates and with a fixed surround. Condition 5: Participants had their eyes closed and stood on a sway referenced force plates and fixed surround. Condition 6: Participants stood with their eyes open with a sway referenced force pate and sway referenced surround. Center of pressure data were sampled at 100 Hz.

Paragraph Number 18

Motivation Testing

Participants were informed that motivation testing was a paper and pencil neurocognitive test. The true intention of the test was not initially revelaed as a motivation test in an effort to reduce and bias that may occur and affect the amount of effort performed on the test. . The Rey's Dot Counting Test was used to test motivation. During the test athletes were shown twelve 5x7 cards. The first six cards have dots placed on them in an unorganized manner and the last six have dots in a grouped manner. The participant was instructed to tell the investigator the correct number of dots on the card as quickly and as accurately as possible. If the athlete said the wrong number of dots, they were instructed to count again. The tester recorded the number of errors the participant made as well as the time the participant took to count the ungrouped and grouped dots.

Paragraph Number 19

Academic Profile

With the athletes consent, we obtained hsGPA and SAT scores from the admissions and registrars offices. We had a small subset of athletes self-report their hsGPA and SAT scores, which we then compared to the scores obtained from the admissions and registrars offices. We observed good reliability between the self-reported and university obtained hsGPA ($ICC_{2,1}$ = 0.991) and SAT ($ICC_{2,1}$ = 0.933). For athletes without university reported hsGPA or SAT we used their self-reported academic information (n=17).

Paragraph Number 20

Data Reduction

CNS Vital Signs raw, standard, and percentile scores are computed by the CNS-VS software for the following domains: Verbal Memory, Visual Memory, Psychomotor Speed, Reaction Time, Complex Attention, Cognitive Flexibility, Processing Speed, Executive Functioning and Reasoning. We chose to use CNSVS age-matched standard scores for all of our analyses. For all standard scores, a higher score reflects better performance. We chose to exclude invalid neurocognitive scores for each of the analyses according to the CNS-VS invalidity guidelines (https://www.cnsvs.com/index.php/clinical-practice).

Paragraph Number 21

The motivation index score was computed as the time taken to count the number of dots per card (12 cards total) plus the number of errors (number of times the athlete incorrectly states the number of dots on the card). Combination Score= Time/12+errors. Lower motivation index scores indicate higher motivation (i.e. correctly identified the number of dots faster with fewer errors).

Paragraph Number 22

The composite score of the SOT is calculated using 14 of the equilibrium scores from each of the six conditions. It is calculated as an average of the (1) mean of Condition 1, (2) the mean of Condition 2 and (3-14) the individual trial scores from Conditions 3 – 6. A higher SOT composite score indicates better balance performance. We excluded outlying SOT composite score values if they were 1.5 times the interquartile range below the 25^{th} percentile. The interquartile range is the range that encloses the middle 50% of the observations. Two participants were found to have invalid scores for the psychomotor speed domain, three for reaction time, seven for reasoning domain, and four for postural control testing.

Paragraph Number 23

In order to determine whether academic profile and motivation influence acute practice effects on postural control measures, we computed change scores for each of the SOT conditions that involve sway referencing (conditions 3-6) by subtracting the equilibrium score from trial three from trial one (change score = trail 3 equilibrium score - trail 3 equilibrium score). Positive scores reflected an increase in postural stability and a negative score reflected a decrease in postural stability.

Paragraph Number 24

Statistical Analyses

All statistical analysis were conducted using SPSS 15.0 (Chicago, IL) with an a priori alpha level of 0.05. In order to determine whether motivation and academic profiled predict neurocognitive performance, we employed nine separate multivariate regression models using each baseline CNS-VS standard score as a criterion variable. Baseline motivation index score, SAT total score, and hsGPA were entered into the model as predictor variables using the enter method. In order to determine whether motivation and academic profiled predict postural control performance, we employed one multivariate regression model using the SOT composite score, as a criterion variable. In order to determine whether motivation and academic profiled predict acute postural control practice effects, we employed four multivariate regression models using the change score of equilibrium score between trial one and three for conditions 3 – 6 as the criterion variables. Baseline motivation index score, SAT total score and hsGPA were entered into the model as predictor variable using the enter method for all regression models. Participants that presented with invalid scores were excluded from specific domain analyses.

Paragraph Number 25

Results

Demographic information for the student-athletes included in analyses are reported in Table 1. Descriptive statistics for the criterion variables are reported in Table 2. Descriptive statistics for predictor variables are reported in Table 3. Statistical results for the nine regression models are reported in Table 4. Multiple regression coefficients are reported in Table 5.

Unweighted hsGPA was a significant predictor of the processing speed standard score ($F_{3,82}$=3.73, p = 0.014; R^2=0.12). Total SAT score was a significant predictor of the complex attention standard score ($F_{3,82}$=3.32, p = 0.024; R^2=0.11) and the Sensory Organization Test (SOT) composite score ($F_{3,78}$=6.31, p = <0.001; R^2=0.20). However, the model explained only 12% of the variance in the processing speed standard score, 11% of the variance in the complex attention standard score, and 20% of the variance in the SOT Composite score.

Paragraph Number 26

Baseline motivation index, hsGPA, and total SAT score were not significant predictors for the domains of verbal memory ($F_{3,82}$=.0.69, p = 0.560; R^2=0.03), visual memory ($F_{3,82}$=0.66, p = 0.578; R^2=0.02), psychomotor speed ($F_{3,80}$=0.64; p = 0.591; R^2 =

0.02) reaction time ($F_{3,79}$=0.07, p = 0.977; R^2=0.003), cognitive flexibility ($F_{3,82}$=1.16, p = 0.330; R^2=0.04), executive functioning ($F_{3,82}$=1.12, p = 0.345; R^2=0.04), and reasoning ($F_{3,75}$=1.82, p = 0.151; R^2=0.07). Likewise, our model did not predict equilibrium acute practice effects between trials 1 and 3 for condition 3 ($F_{3,80}$=1.60, p = 0.197, R^2 = 0.06), condition 4 ($F_{3,79}$=0.27, p = 0.849, R^2 = 0.01), condition 5 ($F_{3,81}$=0.28, p = 0.841, R^2 = 0.01), condition 6 ($F_{3,80}$=0.73, p = 0.538, R^2 = 0.03).

Paragraph Number 27

Discussion

The primary purpose of this study was to determine if academic profile information and motivation test scores could predict baseline and re-test changes in neurocognition and postural control. The most important finding observed was that some of variance in baseline measures of cognitive flexibility, processing speed, and postural control could be explained by baseline motivation index, total Scholastic Assessment Test (SAT) score, and unweighted high school grade point average (hsGPA). However, this model does not appear to predict baseline scores or acute postural control practice effects in a meaningful way. Our model does not explain enough of the variance in these scores to be able to accurately estimate an athlete's baseline performance.

Paragraph Number 28

Although our model did not explain a large percentage of the variance, we suggest that sports medicine professional should at least consider baseline motivation and academic profile when assessing the validity of baseline measures as they do still explain some of the variance [8, 9]. Sports medicine professionals that utilize invalid baseline clinical concussion measures may prematurely return an athlete to play before they have fully recovered from their concussion. This may put athletes at risk of negative postconcussive outcomes, such as second impact syndrome [11, 17]. We were surprised to find that our predictors did not explain a large percentage of the variance for more of the neurocognitive domains as both motivation and the academic profile have previously been shown to have a relationship with neurocognitive performance [8, 9, 13, 18] Other factors, such as intelligence quotient (IQ), current life stresses, or quality and quantity of sleep, and the number of individuals tested at a time, may also influence neurocogntive and postural control performance [12-16].

Paragraph Number 29

Motivation

Motivation was not a significant predictor of baseline test performance for any of the neurocognitive and postural control outcome measures. This could be due in part to the nature of the scoring. Many of the studies that use the Dot Counting Test to measure motivation use specific cut off scores to create groups with normal and suspect motivation [8, 19]. It seems possible that motivation may be an “all-or-nothing” component of clinical concussion measures. Our results contradict previous studies that suggest that increases in motivation should result in increases in neurocognitive and postural control performance [8, 9]. However, there were many differences between these study and ours. Hunt and colleagues [8] used the same Dot Counting Test that was used in this study, used a high school population and compared neurocognitive measures between groups with high and low motivation. Bailey et al. [9] showed that motivation affected clinical concussion measures, but did not complete a separate measure motivation testing, rather the groups were created based on poor or high performance on the baseline test protocols.

Paragraph Number 30

High School GPA

High School GPA was a significant predictor of the processing speed standard score and the SOT composite score. This domain is computed from the Finger Tapping Test and the Symbol Digit Coding Test, which measure the speed and accuracy of simple learned tasks. Previous studies indicate a positive relationship between visuospatial working memory and scholastic testing in a younger population [20]. It seems possible that athletes that are better able to use their visuospatial sketchpad would utilize this as an advantage in the classroom as well as during neurocognitive and postural control assessments. This relationship between visuospatial working memory and scholastic testing could explain the predictive relationships that we observed in this study [20]. When assessing baseline scores for validity, clinicians should expect athletes with higher high school GPAs to have higher scores in domains related to visuospatial working memory. Based on our observed results, an increase of one GPA point accounts for an increase of thirteen points in the processing speed standard score. This increase would be considered clinically relevant. Though the reverse was seen with the composite score of the SOT where there was actually a decrease of six points with an increase of one GPA point.

Paragraph Number 31

We suspect that we may not have observed hsGPA as a significant predictor for a majority of our dependent variables because of the lack of precision in the measure. The high school GPA values reported to us by the admission office varied between one and three decimal places. Because of the varieties in precision, we may not have been able to identify subtle differences between athletes’ academic capabilities. Also, the sample used was fairly homogenous and did not provide a wide variety of both hsGPA and total SAT scores from which to place into the prediction model. Future studies should consider using other measures of academic performance, such as collegiate GPA, National Collegiate Athletic Association GPA or the American Collegiate Test, which are also widely available in a student-athlete population.

Paragraph Number 32

SAT

Total SAT score was a significant predictor of the complex attention standard score, reasoning standard score, and SOT composite score. Like the SAT, baseline clinical concussion measures are cross-sectional. There are also inherent similarities between the mode of administrations of our neurocognitive test battery and the SAT because both are completed on a computer. The Stroop and continuous performance subtests are used to compute the complex attention domain score require the same visuospatial working memory, which have previously been reported to share a relationship with academic profile [20]. Because the reasoning domain standard score is comprised of one version of the Non-Verbal Reasoning Test, test-wiseness could account for SAT's predictive ability of this domain.

Paragraph Number 33

Our results support our hypothesis that the attribute of test-wiseness, often described in academic and educational literature for cognitive and academic tasks, could also be transferred to neurocognitve and postural control tasks typically used during baseline and post-concussion assessment [5, 21]. For example, the SOT utilizes "sway referencing" where the surround and platform move in reference to the movement of the athletes' center of pressure during certain conditions. It seems possible, that athletes with good test-wiseness may more easily become wise to the fact that their sway influences the movement of the platform and surround as they progress through the repetitions of the same conditions multiple times in a single test sessions. It seems possible that athletes that have higher scholastic aptitude as measured by the SAT would be better able at developing strategies for controlling posture during the SOT. Moreover, these results appear to be true for the SOT overall, but do not present as acute practice effects between trials for sway referenced conditions as none of the variables were significant predictors for the change scores for each of the conditions.

Paragraph Number 34

Conclusion

The results of this study suggest that motivation and academic profile predict some, but not a meaningful amount of the variance in baseline clinical concussion measures. Further research is necessary to identify other factors that might help clinicians better assess the validity of an athletes' neurocognitive and postural control measures relative to their individual capabilities. While some of the models yielded significant results, predictive strength of the variables examined are insufficient to recommend replacing baseline testing. However, we suggest that clinicians continue to consider motivation and academic profile when interpreting baseline and post-concussion measures in the clinical decision making process as some of the variance was explained with these variables. Academic profile information can also be easily obtained via a demographic questionnaire prior to baseline testing. We suspect that further research investigating motivation and clinical concussion measures use the motivation index scores as a dichotomous variable rather than a continuous variable. Furthermore, this research shows that there are other influential factors such as intelligence quotient (IQ) or personal perceived risk of sustaining a concussion that affect baseline test performance that have yet to be examined.

Table 1. Demographic Information for sample

	Baseline	
Male (n)	50	
Female (n)	6	
	Mean	SD
Height (in)	69.16	5.02
Weight (kg)	167.23	44.72
Age (years)	18.58	0.52

Table 2. Descriptive statistics for all neurocognitive and postural control variables (criterion variables)

	Baseline		
	n	Mean	SD
CNSVS Standard Score			
Verbal Memory	86	97.98	19.45
Visual Memory	86	99.50	16.22
Psychomotor Speed	84	105.86	11.13
Reaction Time	83	101.30	13.67
Complex Attention	86	95.07	36.40
Cognitive Flexibility	86	98.97	14.48
Processing Speed	86	103.73	15.57
Executive Functioning	86	99.38	13.75
Reasoning	79	99.42	13.72
Sensory Organization Test			
Composite Score	82	76.90	7.07
Condition 3 Change Score	80	-2.71	6.76
Condition 4 Change Score	79	11.46	20.34
Condition 5 Change Score	81	7.84	16.42
Condition 6 Change Score	80	6.78	18.85

Table 3. Descriptive Statistics for the predictor variables

	Baseline	
	Mean	SD
Motivation Index Score	11.61	2.96
Unweighted hsGPA	3.57	0.34
Total SAT Score	1702.33	263.38

Table 4. Statistical Results for Baseline Multiple Regression Models

	F Value†	p	R^2
CNSVS Standard Score			
Verbal Memory	0.69	0.560	0.03
Visual Memory	0.66	0.578	0.02
Psychomotor Speed	0.64	0.591	0.02
Reaction Time	0.07	0.977	0.003
Complex Attention	**3.32**	**0.024***	**0.11**
Cognitive Flexibility	1.16	0.330	0.04
Processing Speed	**3.73**	**0.014***	**0.12**
Executive Functioning	1.12	0.345	0.04
Reasoning	1.82	0.151	0.07
Sensory Organization Test			
Composite Score	**6.31**	**<0.001***	**0.20**
Condition 3 Change Score	1.60	0.197	0.06
Condition 4 Change Score	0.27	0.849	0.01
Condition 5 Change Score	0.28	0.841	0.01
Condition 6 Change Score	0.73	0.538	0.03

Table 5. Multiple regression coefficients

		Intercept	DCT	GPA	SAT
CNSVS Standard Score					
Verbal Memory	B	116.21	-1.02	-2.58	0.002
	t(p)	4.57 (<0.001)*	-1.40 (0.166)	-0.30 (0.764)	0.15 (0.881)
Visual Memory	B	87.38	-0.53	5.16	<0.001
	t(p)	4.12 (<0.001)*	-0.87 (0.388)	0.72 (0.473)	-0.01 (0.993)
Psychomotor Speed	B	101.76	-0.12	5.63	-0.01
	t(p)	6.71(0.001)*	-0.28 (0.780)	1.12 (0.226)	-1.34 (0.184)
Reaction Time	B	96.53	0.21	1.12	-0.001
	t(p)	5.12 (<0.001)*	0.41 (0.685)	0.18 (0.859)	-0.12 (0.902)
Complex Attention	B	60.94	-1.14	-10.13	0.05
	t(p)	1.34 (0.184)	-0.87 (0.384)	-0.66 (0.511)	**2.48 (0.015)***
Cognitive Flexibility	B	84.28	-0.47	2.84	0.01
	t(p)	4.49 (<0.001)*	-0.87 (0.385)	0.45 (0.655)	0.72 (0.474)
Processing Speed	B	54.28	-0.32	13.04	0.004
	t(p)	2.81 (0.006)*	-0.58 (0.565)	**2.00 (0.049)***	0.463 (0.644)
Executive Functioning	B	82.92	-0.37	3.21	0.01
	t(p)	4.65 (<0.001)*	-0.71 (0.478)	0.53 (0.596)	0.70 (0.486)
Reasoning	B	98.63	0.19	-9.47	0.02
	t(p)	5.34 (<0.001)*	0.35 (0.731)	-1.46 (0.148)	**2.31 (0.023)***
Sensory Organization Test					
Composite Score	B	72.52	0.09	-6.81	0.02
	t(p)	8.21 (<0.001)*	0.35 (0.726)	**-2.34 (0.022)***	**4.30 (<0.001)***
Condition 3 Change Score	B	1.18	-0.16	-0.11	0.19
	t(p)	0.13 (0.900)	-1.41 (0.164)	-0.75 (0.457)	1.27 (0.207)
Condition 4 Change Score	B	28.48	0.04	-0.10	0.01
	t(p)	0.99 (0.328)	0.31 (0.756)	-0.64 (0.527)	0.06 (0.955)
Condition 5 Change Score	B	0.83	-0.03	0.13	-013
	t(p)	0.04 (0.971)	-0.23 (0.821)	0.84 (0.404)	-0.81 (0.418)
Condition 6 Change Score	B	3.33	-0.09	-0.04	0.14
	t(p)	0.12 (0.902)	-0.78 (0.438)	-0.24 (0.814)	0.891 (0.376)

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