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The Use of a Visual Motor Test to Identify Lingering Deficits in Concussed Collegiate Athletes

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THE USE OF A VISUAL MOTOR TEST TO IDENTIFY LINGERING DEFICITS IN
CONCUSSED COLLEGIATE ATHLETES

by

ERIK W SANDERS

(Under the Direction of Thomas Buckley, ATC, Ed.D)

ABSTRACT

Context: 1.6 to 3.8 million sports-related concussions occur annually. Athletes who have

suffered a concussion but are symptom free and have returned to baseline on conventional tests

may not necessarily be recovered from the effects of the concussion. The premature return to

play of an unrecovered athlete may increase the risk of a subsequent concussion. Measurement

of upper-limb visual motor coordination has identified lingering deficits following concussion

and so it may provide clinicians with a more sensitive means of tracking recovery. **Objective:**

The purpose of this study was to determine if a visual motor coordination test would identify

lingering deficits in a concussed population of collegiate student-athletes who have returned to

baseline on conventional assessments when compared to healthy controls. **Design:** Prospective

cross-sectional. **Setting:** The biomechanics laboratory of a large southeastern university.

Participants: 13 recently concussed intercollegiate student-athletes, and 13 matched, healthy,

control participants. **Intervention(s):** Each group completed two testing sessions on a visual

motor exam. **Main Outcome Measure(s):** Average score, visual quadrant reaction time, simple

visual reaction time and movement time. **Results:** There was no group interaction in A* score,

quadrant response time, SVRT reaction time and SVRT movement time. There was a significant

improvement in A* score, quadrant response time, SVRT reaction time and SVRT movement

time in both groups between the two sessions. **Conclusions:** There appears to be no deficit in the

visual motor coordination of recently concussed student-athletes after they have recovered according to the standard assessments. The visual motor coordination exam may not provide a useful means of tracking recovery following concussion, due to a substantial practice effect. **Key Words:** Concussion, visual motor, coordination, Dynavision, deficits, reaction time.

INDEX WORDS: Concussion, Visual motor coordination, Recovery, Dynavision

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CONCUSSED COLLEGIATE ATHLETES

by

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4

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DEDICATION

I dedicate this paper to my Lord and Savior Jesus Christ. I dedicate this paper secondly to

Daddy and Mom.

ACKNOWLEDGMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

There are an estimated 1.6 – 3.8 million sports related concussions that occur annually in the United States.[1] Concussions can cause symptoms such as headache, dizziness, blurred vision, and confusion and may also cause impairments in neuropsychological and cognitive function, postural stability, and visual motor coordination.[2-5] A single concussion increases the risk of a second concussion and those who have suffered two concussions are more likely to sustain a third.[6,7] Three or more concussions not only continue to increase the risk of future concussions, but also may cause late life neurological conditions.[6,8-12] To minimize the risk of repeat concussion, health care providers must be able to correctly diagnose a concussion and must also identify recovery from a concussion in order to avoid premature return to play.[13] The standard concussion assessment battery has high sensitivity (89-96%) in the acute diagnosis of concussion, but may have multiple limitations when tracking concussion recovery.[4,14-17] Furthermore, persistent and lingering deficits have been identified in athletes who, following a concussion, have reached their baseline values on standard clinical tests.[18-23] Symptom-free athletes who have passed all standard exams may be returned to play, but may not necessarily be recovered from the effects of a concussion.[19,20,24] Because the premature return to play of an athlete may greatly increase the risk of a repeat concussion and the subsequent pathologies, clinicians need a sensitive assessment that will be able to identify recovery in a concussed athlete.[6,25]

The premature return to participation of a recently concussed athlete may lead to a substantially increased risk of subsequent concussion, as up to 90% of same season repeat

concussions occur within the first 7-10 days post-injury.[6,25] Indeed, there is a 2-6 fold increased risk of a repeat concussion in individuals with a history of a concussion.[6,7] This repeat concussion is more likely to present with loss of consciousness, amnesia, and prolonged disorientation.[26] In addition, an athlete who returns to participation before recovery risks the rare, but potentially fatal, second impact syndrome, in which an athlete receives a second concussion before the first concussion has resolved. In the reported cases of this condition, the victim's brain is believed to rapidly swell in response to the second brain injury and has a 50% fatality rate.[27] Following a second concussion, the individual is at three fold greater risk to sustain a third concussion.[6] Finally, a lifetime history of three or more concussions has been associated with elevated risk of later-life neurological disorders including mild cognitive impairment, depression, and an earlier onset of Alzheimer's disease.[8-10] In the dissection of the brains of collision sport athletes, extensive neurological damage, known as Chronic Traumatic Encephalopathy has been found.[11,12] To protect a concussed athlete from the dangers of repeat concussion, clinicians must not return an impaired athlete to participation and so must be able to objectively and accurately determine when an athlete is recovered and may safely return to participation.

To evaluate a suspected concussion, the 4th International Consensus Statement on Concussion in Sport (4th CIS) recommends the use of a multifaceted concussion assessment battery, which includes the assessment of symptoms, postural stability, neuropsychological performance, and neurocognitive function.[13] A multifaceted approach to diagnosis has been shown to be 89-96% sensitive in the acute identification of the immediate deficits caused by a concussion.[14] When the concussion assessment battery is used to track recovery, the effects of 90% of concussions appear to resolve within 10 days.[28] Unfortunately, the multifaceted battery has multiple limitations and may not be able to correctly track recovery, as deficits have been

shown to linger in the performance of concussed athletes far beyond the 7-10 day window of recovery.[23,29,30] Multiple studies have reported long term deficits that are not identified by the standard assessment battery.[20,23,29,31] Following a concussion, brain electrical activity may possess latencies for up to 12 months, postural instability and gait abnormalities may continue for at least a month, and motor abnormalities may linger for 9 months, even in athletes who have returned to baseline on the standard assessment battery.[20,22,23,29-31] In many of the above studies, deficits are tracked to 28-30 days, which appears to serve as a standard for the identification of lingering deficits.[20,29,30] These findings suggest that the multifaceted assessment is not sensitive to identify complete recovery from concussion.

The multifaceted concussion assessment battery may not be effective in tracking the persistent deficits of concussion, in part, due to its substantial practice effect. Examining the use of the Standard Assessment of Concussion (SAC), balance error scoring system (BESS), and neuropsychological testing reveals that following concussion, participants will generally improve upon their baseline score.[4,15,30,32,33] When tested with the SAC, athletes surpass their baseline score within two days of concussion, while still symptomatic.[4,33] The average BESS score of a collegiate team member may improve by an average of five errors over the course of a season,[15] and even computerized neuropsychological exam performance in memory, reaction time, and processing speed components may improve after repeat administrations.[17,30,32] This practice effect may conceal the subtle deficits that persist following concussion and perhaps explains the elevated same-season re-injury rate.[6,25] In addition, self-reported symptoms may not be a reliable method of establishing recovery. Because of the pressure to quickly return to participation and a lack of concussion knowledge, athletes frequently underreport the acute symptoms of concussion, and also may underreport the duration of symptoms.[16,34] Despite self-reporting

symptom free, over a third of athletes may still demonstrate impairments on neuropsychological testing.[24,32] Self-reported symptoms and standard concussion assessment tools may not be adequate in the assessment of concussion recovery. The use of the concussion assessment battery to establish recovery may allow the return to participation of athletes who are still impaired, and thus at risk of repeat concussion. Therefore, clinicians need a more effective method of identifying recovery.

Visual motor coordination (the use of visual perception to guide and control motor movements) is a complex mechanism that involves multiple neural structures and pathways, including cortical structures, subcortical structures, and the cerebellum.[35] Visual motor coordination is often understood as a three step process: perceiving, deciding, and acting.[36,37] When forming visual perceptions of the surrounding environment, the occipital lobe receives, organizes, and interprets visual sensory information that is collected from the eye through the optic nerve.[38] This visual information is then filtered and sent to the posterior parietal cortex, which uses the visual information to initiate and guide a motor response.[35,39] Depending on the selected response, motor pathways will be activated and movement will occur.[35,37] Some visual information bypasses cortical structures and is transmitted through the superior colliculus directly to motor regions controlling eye and arm movements.[40-42] The medial intraparietal area appears to be responsible for the planning of upper limb reaching movements.[35] Such complex structures may be sensitive to the long-term effects of concussive injury, as the parietal cortex has been shown to possess residual deficits months following a concussion.[43-46]

Concussions appear to cause deficits in visual motor coordination.[5,43,47] Current neuropsychological computerized exams test visual reaction time and visual motor speed, but the components of neuropsychological tests typically only identify deficits up to 2 weeks following

14

concussion, even in studies that also identify lingering deficits in gait and brain electrical activity 30 days following concussion.[30] Additionally, these components only assess the speed of pressing a key on a keyboard, not the complex use of visual information to initiate and guide an upper limb movement.[2,17,30] The measurement of upper arm accuracy and movement speed in a visual motor coordination test has revealed deficits in a concussed population up to one year following the initial concussion and also predicted the course of their recovery at 3 and 6 months post-injury.[43] Prior studies of the assessment of upper limb visual motor coordination have utilized sophisticated equipment that requires extensive, expert analysis.[5,43] These findings suggest that the assessment of visual motor coordination may identify the lingering deficits of concussion and potentially track recovery. If the measurement of visual motor coordination is to be used by clinicians, there needs to an effective means of testing visual motor coordination that can produce data that can be interpreted by the clinician.

The Dynavision is a novel method of measuring visual motor coordination.[48] The Dynavision consists of a large black board (135 cm wide and 167-243 cm tall) that contains 64 lights organized into 5 concentric rings. The participant stands in front of the Dynavision and then reaches to touch the surrounding lights.[48] The concentric rings of light are designed to allow each quadrant of the visual field to be tested, and the lights, which are raised from the surface of the board, provide specific targets that will challenge the visual motor coordination of the participant. Dynavision exams moderately correlate (0.42-0.75) with several common psychomotor tests, such as the pursuit rotor task, the Minnesota manual dexterity test, and the ring replacement test.[48] Dynavision exams have shown good test-retest reliability (0.88) and ICC values (0.75).[49-51] While expensive, the Dynavision may effectively measure the visual motor coordination of participants and produce easily interpretable results. Therefore, its use in the

assessment of concussed athletes should be investigated. To assess the efficacy of the Dynavision as a means of identifying lingering deficits, the system must be able to detect deficits in a concussed population once they have returned to baseline on all standard exams and at 30 days post injury.

Concussions can be diagnosed with 89-96% accuracy with the multifaceted concussion assessment battery.[14] However, the assessment tools used to diagnose concussions have substantial limitations when used to track recovery from concussion. Tests of visual motor coordination may provide a suitable method of identifying lingering deficits.[4,15,16,43] The purpose of this study was to determine if visual motor coordination tests, through use of the Dynavision, would identify lingering deficits in a concussed population of collegiate student-athletes in average score or visual response time when compared to healthy controls. The hypothesis of this study was that the visual motor coordination tests would identify lingering deficits in the average score but not simple visual reaction time in a concussed population, because tests of simple visual reaction time have been shown to return to baseline within 1-2 weeks.[2,17]

CHAPTER 2

METHODS

Participants

There were 13 recently concussed student-athletes (male: 7, age: 18.9 $\pm$ 0.7 years, height:

175.5 $\pm$ 12.4 cm, mass: 75.5 $\pm$ 23.2 kg, concussion history: 0.38 $\pm$ 0.77 concussions) and 13

control student-athletes (male: 7, age: 19.3 $\pm$ 1.1 years, height: 173.5 $\pm$ 11.9 cm, mass 75.8 $\pm$

19.9 kg, concussion history: 0.31 $\pm$ 0.48 concussions). (Appendix C, Table 1) The control

participants were matched by gender, sport, position and age (within 3 years) and there were no

significant differences between groups for any of the demographic characteristics. The inclusion

criteria for all participants was that each concussed participant must be a current, collegiate

student- athlete and have recently sustained a concussion that was identified by an athletic trainer

and diagnosed by a physician. Each control participant was a collegiate student-athlete, matched

to a concussed participant according to gender, sport, position, and age within three years. The

exclusion criteria was any self-reported visual, vestibular, or neurological conditions prior to

concussion that would have interfered with performance (including a previous concussion within

three months prior to the current injury), and a current upper extremity injury, as identified by

the health history survey.[43] (Appendix C, Figure 1) Corrected vision did not exclude participants

from this study, but use of corrective lenses, if applicable, was standardized across testing

sessions. In addition, each concussed participant was required to have passed the standard

assessment battery within fourteen days.[13] Three potential participants were excluded because

their recovery according to the standard assessment battery took longer than 14 days to resolve, 2

refused to complete the research, 1 had a long term upper extremity injury, and 2 potential

participants were excluded due to incomplete data. All participants provided written informed

consent as approved by the university's IRB.

Instruments

The Dynavision (D2 model, West Chester, Ohio, USA), a novel instrument that is used to

assess and train visual motor coordination, was used in this study. The core of the Dynavision is

a large black board that extends 165 cm in width and 120 cm in height. The board contains 64

lights, organized into 5 concentric rings, and a 7.5 cm wide LED screen positioned 8 cm above

the center of the board. The participant stands at a self-selected distance from the light-board,

within easy reaching distance of all the lights. The light-board can be raised or lowered to adjust

to the participant's height. (Appendix C, Figure 2)

Two Dynavision exams were used during this study. The first exam was the A* exam, which

tests how quickly and accurately a participant can reach to touch visual stimuli. The A* exam

has a test, retest reliability of .88 and an ICC of .75.[50,51] The A* exam's correlation with

traditional visual motor coordination exams ranges from .42-.75.[48] The validity of this exam has

not yet been studied. The second exam was the Dynavision's simple visual reaction time (SVRT)

test, which uses two of the lights from the system's board. These lights are 30 cm apart.[48] No

reliability or validity numbers are available for the SVRT test.

A confrontation visual field test, Donder's test, was used to rule out gross visual field

dysfunction in the participants.[52,53] During this exam, the clinician faced the participant and uses

his hands to roughly estimate the size of the participant's visual field. This exam is sensitive to

35% of field deficits of any kind, and is recommended in optometrist literature for use as a rapid screen to assess for any gross deficits of visual field.[52,53]

The weigh-beam, eye level scale from Detecto Scales (Webb City, MO, U.S.A.) was used to measure the height and weight of the participants.

The Graded Symptom Checklist (GSC) is a tool that quantifies the amount and severity of post-concussion symptoms (Appendix C, Figure 3). It is a brief form that lists 22 symptoms, and for each symptom, participants can indicate the current severity of the symptom on a 6-point Likert scale. Zero indicates that the participant is not experiencing the symptom, and 6 indicates that the symptom is severe.[54] The GSC's criterion validity ranges from .68 to .96, its sensitivity is .04-.96, and its specificity is 1.00.[55,56]

This study utilized the Sony Handycam video camera (Model number HDR – PJ580V, China) to record the participants' trials for retrospective analysis. The camera was placed at a 45-degree angle from the Dynavision, to record the entire lightboard as well as the participant's trunk, head and both arms.

Procedures

For a single fall and winter athletic season, the athletic training staff of the university contacted the research team when a student-athlete was determined to have a concussion by an athletic trainer which was diagnosed by a physician. The university athletic training staff baseline tested every intercollegiate student-athlete at the beginning of their collegiate athletic career using the Immediate Post-concussion Assessment and Cognitive Testing (ImPACT), the Standardized Assessment of Concussion (SAC), and the Balance Error Scoring System (BESS). When a student athlete sustains a concussion, these exams are re-administered and compared to

the baseline performance. If the student-athlete performs worse on an exam, it is considered a positive test. Student-athletes who suffered a concussion were reevaluated using the above exams within 48 hours to diagnose the concussion, and then the battery of exams was used to track the student-athlete's improvement following concussion. The Graded Symptom Checklist (GSC) was administered daily to track symptom progress.

When a student-athlete became asymptomatic, the SAC and BESS were administered daily until scores reached baseline, and ImPACT was administered two times a week until the student-athlete reached baseline. Once a student-athlete returned to baseline on each exam, they were allowed to progress to return to play, provided they had no further symptoms arise. The student-athlete began with light aerobic activity and progressed daily to more difficult activity until they returned to full activity in their sport, based upon the recommendations of the 4th international consensus statement.[57] The athletic training staff asked the participant to be part of this study. If the participant agreed, they were contacted by the research team to set up the first testing session. The participants were tested within one or two days after they had returned to baseline on every exam (T1), which was before they had fully returned to play.

T1 took place at a biomechanics lab, located in the main athletic department's facility of the university. The participant completed a brief health history form and then was measured for height and weight. (Appendix C, Figure 1). The researcher then used Donder's test to assess the participant's visual field.[52,53] To perform this test, the researcher and participant sat facing one another. The participant covered one eye and focused the vision of the other eye on the researcher. The researcher stretched out his hand and arm beyond the field of vision of the participant's eye, then slowly brought the hand within the field of vision of the participant. The participant reported when he was able to see the researcher's hand, and the researcher then used

20

the location of his hand to estimate the size of the participant's field of vision in the superior, inferior, temporal and nasal fields. The procedure was then repeated on the opposite eye. If the participant's field of vision was less than the researcher's field of vision, or if there was a bilateral difference, than it was considered a positive test.

The participant was given a GSC and asked to fill it out themselves based on how they were currently feeling. The participant would complete a GSC before and after both testing sessions. The participant then began his or her testing on the Dynavision. The testing sessions was recorded for retrospective analysis of excessive body movement during the tests. This information was available to potentially remove outliers from the data.

The researcher described the A* exam and how to perform best on it.[48] The participant was instructed to keep his eyes in the center of the screen, use his peripheral vision as much as possible, use any part of his hand to hit the lights and stand at a distance from the board where he could comfortably reach the outermost ring of lights. During the A* exam, a peripheral light would randomly turn on and the participant must quickly reach to turn the light off by pressing it. Once the participant does so, another light would instantly turn on. The participant's goal was to touch as many lights as possible within 60 seconds.[48] This study followed the warm up protocol established by prior research by Klavora, in which the participant completed 30-second warm up trials of A* until the most recent score did not improve upon the previous score in order to reduce a practice effect).[50] The concussion and control groups required an average of 3.1 ($\pm$ 1.0) and 3.7 9 ($\pm$ 0.9) (range: 2-5) warm up trials for the first testing session, respectively. Once the scores on the 30 second trials stopped improving and leveled out, the participant would complete five full 60 second trials of the A* exam.[50]

Following the trials of the A* exam, the participant completed trials of the SVRT test. During the SVRT test, the participant held down a button on the center of the board, then, as soon as a button 30 cm away lit up, released the original button and reached to touch the light as quickly as possible with the same hand.[48] The participant completed 3 warm up trials and 5 recorded trials of the SVRT test on each hand. The participant completed a second GSC, and then was asked to schedule the second appointment thirty days (plus or minus one day) after the date of injury.

On the day of the second test (T2), the participant arrived and completed a GSC. The researcher reviewed the A* exam and how to perform well on it. The participant completed 30-second warm up trials until the most recent score was equal or worse than the prior score. Once this point was reached, the participant completed five trials of the A* exam.[50] The concussion group and the control group required 3.0+0.9 and 3.4+1.0 practice trials for the second testing session, respectively. Next, the participant completed 3 warm up and 5 recorded SVRT trials on each hand. Finally, the participant completed a final GSC.

The control participants were selected through the intercollegiate athletics department at the university. The university sports medicine staff was asked to provide possible control participants, matched by gender, age within three years, sport, and position.[43,58] Once a potential control participant had been identified, he or she was asked by the university staff to participate in the study. If they agreed, the research team contacted the participant to schedule the initial testing session. During T1, the procedures of the research were explained, the participant filled out a brief health history survey, and the participant's visual field was assessed with Donder's test. The same testing procedures were followed as for the concussed group. The time lapse between the two sessions were matched with the time between a concussion participant's two testing sessions. The control participants were asked to fill out a GSC before and after each

22

testing session. The second testing session followed identical procedures as the concussion group.

Data Analysis

This was a prospective, longitudinal study. The independent variables of this study were group (concussed group and control group) and testing session (T1 and T2). Each testing session provided seven dependent variables. Five dependent variable were taken from the A* exam. The first dependent variable was the mean score across the five A* trials for a testing session. An A* score is the number of lights that the participant turned off within a 60 second trial. The remaining 4 dependent variables from the A* exam were the mean response times over the five A* trials for each quadrant of the light board. The Dynavision divides the lights into four quadrants: upper left and upper right (UL and UR), and lower left and lower right (LL and LR).

Two dependent variables were provided by the SVRT test: the reaction time (the time required for the participant to perceive the light and lift his hand from the starting button) and the movement time (the time between releasing the original button and pressing the target light). The reaction time for both hands was averaged across the five trials of each testing session. The movement time for the mean of the 5 trials for each testing session. Each session thus yielded a total of seven dependent variables: average A* score and average response time (the average amount of time required for the participant to perceive and hit the lights in each quadrant) in the UL, UR, LL, and LR quadrants of the light board during the A* exam, as well as the average reaction time and average movement time during the SVRT.

Statistical Analysis

    Using SPSS v. 21, descriptive statistics were run on the participant's demographic information and all dependent variables. Seven 2 (group) x 2 (session) repeated measures Analysis of Variance (ANOVA) were used. These tests were used to compare the A* average score, the response time in each of the 4 quadrants during the A* exam, as well as the reaction time and movement time during the SVRT test of both groups across the two testing sessions. The alpha level was set at .05. Normality of the data was checked through visual investigation of histograms and through Kolomogrov-Smifnoff tests (the alpha level was set at .05). The data was normally distributed.

CHAPTER 3

RESULTS

There was no difference in the duration of time between testing sessions for the concussion and control (22.8 $\pm$ 3.5 and 23.2 $\pm$ 3.7 days, respectively, $F(1, 24)=0.043$, $p=.78$). (Appendix C, Table 1) There was also no difference between the mean GSC score for between groups at T1 (1.2 $\pm$ 3.9 GSC and 0.1 $\pm$ 0.3 GSC pre-testing, and 0.9 $\pm$ 2.5 GSC and 0.0 GSC post-testing, $F(1,24)=4.0$, $p=0.29$ and $F(1,24)=4.9$ $p=0.19$) or at T2 (0.0 GSC and 1.7 $\pm$ 5.5 GSC pre-testing and 0.0 GSC and 1.5 $\pm$ 5.0 GSC post-testing, $F(1,24)=4.9$, $p=.28$ and $F(1,24)=5.1$ $p=.28$). (Appendix C, Table 2) All participants passed Donder's test.

There was no interaction between session and group for A* score ($F(1,24)=0.32$, $p=.58$, $\eta^2=0.013$). There was a significant main effect for session ($F(1,24)=38.1$, $p<.001$, $\eta^2=.61$), but no main effect for group ($F(1,24) = .01$, $p=.92$, $\eta^2<0.001$). (Appendix C, Table 3) There was no difference between mean A* score for concussion and control groups at T1 (76.8 $\pm$ 8.5 and 75.8 $\pm$ 12.4 hits) or T2 (82.6 $\pm$ 10.9 and 82.7 + 11.6 hits). (Appendix C, Table 4, Figure 4)

There was no interaction between session and group for the response time in the UL quadrant ($F(1,24)=0.94$, $p=.34$, $\eta^2=.04$). There was a significant main effect for session ($F(1,24)=8.4$, $p<.001$, $\eta^2=.26$), but no main effect for group ($F(1,24)=0.081$, $p=.78$, $\eta^2=0.003$). (Appendix C, Table 3) There was no difference between UL response time for concussion and control groups at T1 (0.77 $\pm$ 0.10 and 0.79 $\pm$ 0.13 s) or T2 (0.75 $\pm$ 0.10 and 0.75 + 0.10 s). (Appendix C, Table 4, Figure 5) There was no interaction between session and group for the response time in the UR quadrant ($F(1,24)=0.92$, $p=.35$, $\eta^2=.04$). There was a significant main effect for session ($F(1,24)=12.9$, $p=.001$, $\eta^2=.35$), but no main effect for group ($F(1,24)=0.72$, $p=.41$, $\eta^2=0.029$).

(Appendix C, Table 3) There was no difference between UR response time for concussion and control groups at T1 (0.74 $\pm$ 0.10 and 0.79 $\pm$ 0.13 s) or T2 (0.70 $\pm$ .10 and 0.72 $\pm$ 0.10 s). (Appendix C, Table 4, Figure 5) There was no interaction between session and group for the response time in the LL quadrant ($F(1,24)=0.12$, $p=.73$, $\eta^2=.005$). There was a significant main effect for session ($F(1,24)=20.6$, $p<.001$, $\eta^2=.46$), but no main effect for group ($F(1,24)<0.001$, $p=.99$, $\eta^2<0.001$). (Appendix C, Table 3) There was no difference between LL response time for concussion and control groups at T1 (0.81 $\pm$ .10 and 0.81 $\pm$ 0.14 s) or T2 (0.74 $\pm$ 0.12 and 0.74 $\pm$ .10 s). (Appendix C, Table 4, Figure 5) There was no interaction between session and group for the response time in the LR quadrant ($F(1,24)=0.41$, $p=.53$, $\eta^2=.017$). There was a significant main effect for session ($F(1,24)=30.3$, $p<.001$, $\eta^2=.56$), but no main effect for group ($F(1,24)=0.003$, $p=.96$, $\eta^2<0.001$). (Appendix C, Table 3) There was no difference between LR response time for concussion and control groups at T1 (0.80 $\pm$ 0.09 and 0.81 $\pm$ 0.17 s) or T2 (0.72 $\pm$ 0.11 and 0.71 $\pm$ 0.09 s). (Appendix C, Table 4, Figure 5)

There was no interaction between session and group for SVRT test reaction time ($F(1,22)=0.56$, $p=.46$, $\eta^2=.025$). There was a significant main effect for session ($F(1,22)=4.9$, $p<.05$, $\eta^2=.18$), but no main effect for group ($F(1,22)=0.34$, $p=.57$, $\eta^2<0.015$). (Appendix C, Table 3) There was no difference between reaction time for concussion and control groups at T1 (0.32 $\pm$ 0.05 and 0.30 $\pm$ 0.04 s) or T2 (0.29 $\pm$ 0.05 and 0.29 $\pm$ 0.04 s). (Appendix C, Table 4, Figure 6) There was no interaction between session and group for SVRT test movement time ($F(1,22)=0.72$, $p=.40$, $\eta^2=.03$). There was no significant main effect for session ($F(1,22)=4.9$, $p=.67$, $\eta^2=.008$) or group ($F(1,22)=0.06$, $p=.81$, $\eta^2<0.003$). (Appendix C, Table 3) There was no difference between reaction time for concussion and control groups at T1 (0.24 $\pm$ 0.09 and 0.26 $\pm$ 0.08 s) or T2 (0.29 $\pm$ 0.05 and 0.29 $\pm$ 0.04 s). (Appendix C, Table 4, Figure 7)

CHAPTER 4

DISCUSSION

The purpose of this study was to investigate the use of the Dynavision to assess for lingering deficits visual motor coordination in a population of recently concussed collegiate student-athletes when compared to healthy control participants. The hypothesis of this study was that the visual motor coordination tests, using the Dynavision, would identify lingering deficits in A* average score but not in simple visual reaction time or movement time in a concussed population. Based on the results of this study, the A* exam may not provide a suitable method of tracking recovery in a concussed population due to a strong practice effect. The main finding of this study is that there was no group interaction for A* score but there was a significant improvement in the score of both the concussion and control groups across the two sessions. A secondary finding of this study was that there was no group interaction for quadrant response time. There was a significant improvement in all four quadrants for both groups between sessions. An additional finding of this study is that there was no group difference in reaction time or movement time. There was an improvement between sessions in the reaction time of both groups, but no improvement in movement time across sessions. If the visual motor coordination of recently concussed student-athletes is not inhibited after the student-athlete has returned to baseline on the standard assessment battery, then clinicians should feel more confident in current return to play procedures, knowing that recently concussed student-athletes may have full visual motor coordination capability.

The A* exam and SVRT test performance in this study is within the ranges provided by previous literature.[48,50,51,59] Prior research has reported A* scores that range from 67.0-93.8 hits.

No previous literature has reported the response time of each individual quadrant during the A* exam, but Wells reported that the average overall response time during the A* exam ranges from 0.64 $\pm$ 0.09 to 0.75 $\pm$ 0.64.[51] The current findings for total response time, .54 ($\pm$ .1), compare well to the values that Wells and Vesia have reported using the Dynavision: .55 and .50 s respectively.[48,51] No previous literature has examined the use of the Dynavision in a concussed population, but previous studies have found deficits in visual motor coordination using other visual motor coordination tasks. This study found no group differences, indicating that the concussion group of this study had no deficits in visual motor coordination at T1 and T2. It is possible, however, that a practice effect may have affected the results. Previous literature has indicated that the Dynavision does not have a practice effect after 3 trials and that a baseline score can be attained after only 2-3 trials of the A* exam.[48,50,51,59] The findings of this study suggest otherwise; the main effect for session indicates that both groups improved their scores due to the repeat administrations of the exam. Even with 3-5 30 s warm up trials, 5 full A* exam trials and an average of 3 weeks between the two sessions, there was still an improvement of 5.8 and 6.9 hits in the score for concussion and control groups, respectively. The prior studies have used only 4-6 total trials of the exam in their testing protocol.[48,50] It is likely that the additional trials in this current study have made the practice effect of the A* exam more apparent. When considering that an increased number of targets in a reaching task may increase the amount of time required for the motor system to adapt, it is not surprising that the Dynavision A* exam would require many trials for the practice adaptation to occur.[51,59-61] When the mean performance of each of the ten total trials (from the two sessions combined) is compared, there is a clear trend of improvement through trial seven. (Appendix C, Figure 8) The practice effect of the A* exam would make it difficult to identify minute deficits; the exam may have largely tested how quickly

the participants could adapt to the novel motor task and may not have assessed each group's

absolute best performance across the two sessions of five trials each. There were no group

differences; the two groups adapted to the exam at a similar pace, but the practice effect may still

limit this study's claim that there are no group differences in visual motor coordination following

recovery according to the standard assessment battery as both groups were improving until trial

seven. (Appendix C, Figure 8) A testing protocol should be developed that would reduce the

practice effect in order to better assess the best performance of the participants' visual motor

coordination.

Hick's law dictates that as the possible responses in a reaction time test increases, the reaction

time increases as well.[62] This indicates an increased load on the central nervous system's

planning and initiation of the motor response.[62,63] It was thought that the Dynavision A* exam,

with 64 lights at five distances and 16 angles from the center of the board, would provide an

appropriately challenging test of visual motor coordination to identify deficits following

concussion. However, the results of this study indicate that the concussion group had no deficits

in visual motor coordination. Heitger identified deficits in a concussed population in visual

motor coordination, but used a population that was still symptomatic after twelve months, even

though they presented with Glascow Coma Scale scores of 13 or above.[5,43] The participants in

this current study were asymptomatic within 14 days.[43] Asymptomatic, recently concussed

collegiate student-athletes may not suffer from the same lingering deficits as Heitger's

population of symptomatic emergency room patients.

There was no group interaction in reaction time or movement time, indicating that post-

concussion deficits in visual reaction time may recover along the same timeline as the standard

assessment of battery. Prior research has used simple reaction time as a component in the

neuropsychological testing of concussed student-athletes and has found that visual reaction time appears to recover within two weeks following injury.[2,17,30] The addition of a reaching and targeting component did not identify any lingering deficits in reaction time or movement time. In this study, both groups improved substantially in reaction time over the two sessions, but there was no improvement in movement time. The reaction time is thought to reflect the amount of time required for the central nervous system to perceive the stimulus and decide upon and initiate the motor response.[61-63] The movement time reflects how long is required for the peripheral nervous system to complete the required task by recruiting the appropriate motor units.[62,63] Fitt's law dictates that as an individual attempts to respond faster, they will be less accurate, and, conversely, greater accuracy comes at a price of decreased speed.[64] During the trials, the participants would often attempt to increase the speed of hand movement, but would then make more errors. The participants which achieved the 2 lowest movement times during the 10 total trials (across the 2 sessions) also had 2 of the highest movement times; they attempted to hit the light so quickly that they would miss the light on some of the trials, based upon retrospective video analysis. These errors, such as missing the light, would cost time and erase any potential gains from increased movement speed. Therefore, movement time may not improve because increased arm and hand speed led to more frequent errors and did not improve average movement speed. The improvement in reaction time for both groups may then indicate an increased speed in the central nervous system planning the direction and magnitude of arm movement in response to the target location.[60-62] Reaction time may recover in recently concussed collegiate student-athletes by the time they have passed the standard assessment battery. If collegiate student-athletes do not have lingering deficits in visual-motor coordination

or simple visual reaction time or movement time, then clinicians may have more confidence in the current recommended return to play protocol.[65]

There were several limitations to this study. First, there was no baseline data available. It was not feasible to baseline all of the student-athletes at the university on the Dynavision, so this study was therefore unable to compare the visual motor performance of recently concussed student-athletes to their own performance prior to the concussion. Instead, closely matched healthy control participants were used. Though the control participants were matched on important characteristics, the may not have had the same visual motor coordination capability. Therefore, without baseline performance it is difficult to understand the effect of concussion on visual motor coordination. Future research should investigate the use of the Dynavision in the assessment of concussed student-athletes with the benefit of baseline performance. A second limitation of this study was a lack of motivation in the performance of some of the participants. Subjectively, some participants appeared far more competitive and motivated to do their best during the exams than others. This study used NCAA student-athletes as participants and it is against NCAA regulations to provide incentives for participation in the study. It was difficult to get the participants to perform as well as possible, even though the research team constantly encouraged the participants to put forth full effort during the trials. Decreased motivation may have led to decreased performance, which may have affected the results. However, no statistical tests were close to significance, and the performances of the concussion and control groups were similar to prior research. Finally, this study was delimited to the amount of concussions that occurred at the university. After some participants were excluded or refused to participate, this study had relatively low participant numbers. However, other studies, when assessing a concussed population using a novel task have used similar numbers of participants: Locklin used

10 experimental and 10 control participants, and Eckner used 9 experimental participants.[58,66] In addition, the majority of the statistical tests had adequate power (0.56-1.0). (Appendix C, Table 2)

Clinicians need an effective means of tracking recently concussed athletes to ensure a safe return to participation. It was thought that the use of the Dynavision to test the visual motor coordination of recently concussed student-athletes would identify lingering deficits in visual motor coordination and enable clinicians to track the recovery of student-athletes. There were no group differences between the control participants and the recently concussed participants, indicating that the recently concussed participants had no deficits in visual motor coordination by the time they had returned to baseline on the standard assessment battery. The A* exam does have a substantial practice effect, which may limit its usefulness in tracking the recovery of recently concussed collegiate athletes. However, this should give clinicians greater confidence in the standard return to play recommendations, as visual motor coordination is very important to safely participate in sport. Further research should be conducted to investigate more thoroughly the effects of concussion on visual motor coordination to determine if the standard assessment battery is providing a safe timeline for return to play.

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APPENDIX A

ASSUMPTIONS, DELIMITATIONS AND LIMITATIONS

Assumptions

This study assumed that participants were honest on their health history survey, and put forth full effort on each exam.

Limitations

The first limitation of this study was that there was baseline performance for the participants on the exams. However, it would not have been feasible to baseline test all student-athletes at the university. A second limitation was that the participants may not have been fully motivated to perform as well as possible on the visual motor exams. However, it would have violated NCAA regulations to offer any incentives to the participants. A final limitation is that the study used a relatively small sample size. The majority of the statistical tests had adequate power (0.56-1.0). (Appendix C, Table 2)

Delimitations

This study was delimited to collegiate student-athletes. Secondly, this study only examined the visual motor coordination of these student-athletes, and did not analyze any data from conventional assessment techniques. Finally, the sample only examined visual motor coordination up to one month following injury.

Research Questions

The first research question of this study was would the concussion and control groups perform differently the A* exam at either testing session? Would there be a main effect for either session or group? Would there be a group interaction? An exploratory question was would the recently concussed student-athletes perform differently on a specific quadrant of the visual field when compared to the healthy controls at either testing session? Would there be a main effect for session or group? Would there be a group interaction? The hypothesis was that the concussed group would perform worse on the visual motor coordination exam than healthy matched controls at both testing sessions.

The second research question of this study was would the concussion and control groups perform differently the SVRT test at either testing session? Would there be a main effect for either session or group? Would there be a group interaction? The hypothesis was that there would be no group differences in performance on the SVRT test.

APPENDIX B

LITERATURE REVIEW

Introduction

An estimated 1.6-3.8 million sport related concussions occur in the United States each year.[1] This figure may underestimate the problem, because as many as 50% of concussions may go unreported.[34] Much attention has been devoted to concussions in recent years, and news has reached the public of the impact of concussions on youth sports, the effects of repeat concussions on NFL players, and news of the rare but potentially fatal second impact syndrome.[68-70] Many misconceptions regarding concussion still persist in the minds of many athletes, coaches, and even physicians.[34, 71, 72] Here, the pertinent literature regarding the effect and impact of sports related concussion will be presented, and then this review will examine the information regarding the assessment, management and return to play of concussed athletes.

Physiology of concussion

Concussions, while they are considered mild traumatic brain injury, cause detrimental effects on the brain. These effects are believed to be caused by a neurometabolic cascade that has been observed in the brains of animals.[73] The initial blow triggers the neurometabolic cascade, which starts with the release of excitatory neurotransmitters. In cells effected by the concussive impact, the release of the excitatory neurotransmitters leads to a massive efflux of potassium from the cell and an increase in concentration of calcium within the cell. When the concentration of potassium within the cell drastically decreases, the sodium potassium pump must work hard to

39

attempt to re-establish homeostasis. This work requires adenosine triphosphate (ATP), which

occurs in the presence of decreased cerebral blood flow within the concussed brain. The disparity

between increased demand for energy and decreased supply of energy through blood flow is

further complicated by the presence of increased calcium, which accumulates in the

mitochondria, thus inhibiting the ability of the mitochondria to oxidatively produce ATP. As the

mitochondria produces less ATP, the supply of energy decreases even further. All of these

factors combine to produce an energy crisis within the cell. The end result of this crisis may be

apoptosis, which is the self-destruction of a cell. This energy crisis leaves the brain in a

vulnerable state for 7-10 days following the initial injury. In addition, the brain suffers a decrease

in magnesium levels, axonal damage, and lactic acid accumulation.[73]

Definition

It is reasonable to draw the conclusion from the above information that mild traumatic brain

injury is not a "ding," a "bell-ringer," or anything less than an actual injury to the brain.

Concussion has been defined in many different ways by many different authors. The standard

definition of concussion is drawn from the fourth international consensus statement, which states

that "Concussion is a brain injury and is defined as a complex pathophysiological process

affecting the brain, induced by biomechanical forces. Several common features that incorporate

clinical, pathologic and biomechanical injury constructs that may be utilized in defining the

nature of a concussive head injury include: 1. Concussion may be caused either by a direct blow

to the head, face, neck or elsewhere on the body with an 'impulsive' force transmitted to the

head. 2. Concussion typically results in the rapid onset of short-lived impairment of neurological

function that resolves spontaneously. However, in some cases, symptoms and signs may evolve

over a number of minutes to hours. 3. Concussion may result in neuropathological changes, but the acute clinical symptoms 4. Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course. However, it is important to note that in some cases symptoms may be prolonged."[74]

Concussion deficits

Concussions cause deficits in many aspects of brain function.[3, 75] The most commonly assessed and measured impairments may be found in neurocognitive ability, neuropsychological function, and postural stability. The neurocognitive damage of concussion was supported by McCrea, who demonstrated that concussed athletes will have a 4-6 point drop from an average baseline of 26 on the Standardized Assessment of Concussion (SAC) immediately following the concussive blow.[3] Maddocks has demonstrated that an athlete suffering from concussion will be disoriented and show a deficit in recent recall. Concussed athletes had difficulty answering questions such as "Which quarter is it?" The evidence demonstrates that concussion may leave athletes less cognitively aware and able.[76]

Concussion has also been shown to decrease neuropsychological function. Covassin examined the neuropsychological performance of 76 concussed high school athletes using the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT). He discovered that those athletes who sustained a concussion demonstrated a one tenth of a second increase in reaction time, a one tenth decrease in the visual memory composite, a five one hundredth decrease in the verbal memory composite, a ten point decrease in motor processing speed, and a fifteen point increase in symptom score.[4] 72 concussed athletes, in Guskiewicz's study of

postural and neuropsychological deficits, demonstrated decreased performance on every exam in a pen and paper neuropsychological testing battery.[75] McClincy used 104 concussed athletes and measured them using ImPACT. His population demonstrated deficits in every component of the ImPACT following the concussion: a one tenth of a second increase in reaction time, a 10 point decrease in the visual and verbal memory composites, a 5 point decrease in processing speed, and a 20 point increase in symptom score.[17]

Balance deficits and postural control difficulties following concussion have been demonstrated by Slobounov, Gao, Cantena and Guskiewicz, among others.[19, 20, 29, 75, 77] Slobounov, in his study of balance following concussion, used virtual reality technology and force plates to identify deficiencies in an athlete's balance following concussion. He discovered that balance difficulties can persist for 30 days following concussion.[29] Gao's study showed that the center of pressure of a concussed athlete has significantly greater randomness in its sway during static stance, and the area that contains the movement of the center of pressure is greater.[19] Cantena's review evaluated evidence regarding the control of balance during dynamic tests such as walking. The evidence shows that a concussed athlete's center of mass will have increased medial to lateral sway, potentially indicating increased instability.[77] Guskiewicz studied the balance of 72 participants and discovered diminished performance on both the balance error scoring system (BESS) and the Neurocom Smart Balance Master System. The participants had a group baseline of 12 on the BESS, which increased to 15 following concussion.[75] The balance assessment most commonly used by athletic trainers is the BESS, although it may have low intra- and inter-rater reliability and a high minimum detectable change.[78, 79, 80, 81] The BESS has been used in many studies to identify deficits in postural stability acutely following concussion and may track deficits up to 3 to 5 days post injury.[28, 33]

42

Concussions can cause symptoms. Headache may be the most common, as over 90 percent of concussed athletes will report this symptom.[2, 76, 82] Visual disturbances, nausea, inability to think clearly, and dizziness are also commonly reported as symptoms.[2, 76, 82] Symptom reporting may be one of the most frequently utilized methods by clinicians.[78, 79] Typically, symptoms will increased following a concussion, and will persist for 7 to 10 days.[28, 33]

Concussion Impacts

The physics of concussive impacts have been studied in football at the youth, collegiate and professional levels.[83-85] Pellman reconstructed NFL hits in a biomechanics laboratory and was the first to quantify the forces involved in a concussive football hit. The concussive hits that were reconstructed had an average impact linear force of 98g, an average peak rotational acceleration of 6500 rad/s^2, an average peak velocity of 9.3 m/s, and an average velocity change of 7.2 m/s. These figures indicate a massive collision, with accelerations and velocities that are similar to the forces in an automobile accident; however, these forces are only applied for about 15ms.[83, 86] Hits to the front of the facemask may result in the highest average impact velocity, and hits to the side of the helmet or facemask may have the highest rotational acceleration.[86] Hits to the back of the helmet may involve the highest change in velocity because they often involve the helmet rebounding off of the ground.[86] Broglio examined hits in high school using accelerometers in helmets. His article reported that the average non-concussive hit in high school is around 23 – 25 g, and the average rotational acceleration is 1400-1700 rad/s^2.[84] In collegiate football, as demonstrated by Mihalik, the non-concussive hits involve slightly less average linear acceleration (22g).[87] The magnitude of a concussive hit averaged 102g according to Guskiewicz in his study of division I collegiate football.[88] Youth football impact

biomechanics have been measured by Daniel, though with a small sample size.[85] The hits averaged 18g, although some impacts approach high school and collegiate levels with forces of up to 80g.[85]

Despite the mass of evidence that has accumulated regarding the biomechanics of concussive impacts in football, there remains no known connection between the force of a hit and the severity of a concussion, nor does there appear to be a threshold of force that causes a concussion. Using 88 division 1 football players, Guskiewicz compared the force of concussive impacts as measured by the Head Impact Telemetry system to the severity of concussion. No correlation between impact magnitude and concussion severity, measured through symptom score, was found. These findings indicate that there are factors beyond impact magnitude that determine whether an athlete sustains a concussion and how severe the concussion will be.[88]

<div style="text-align:center">Concussion Epidemiology</div>

The epidemiology of concussion has been extensively studied in sports, particularly in football. Shankar reported that concussions were by far the most common head and face injury suffered by collegiate and high school football players, making up 96.1% of head and face injuries, which, according to the same study, comprise 11.5% of total injuries.[89] An estimated 55,000 concussion occur annually in high school football.[90] Marar, in her study of concussion epidemiology among 20 high school sports, determined that concussions made up 13.2% of all injuries in her sample.[82] Clearly, concussion is a common injury, particularly in contact sports, that clinicians must be comfortable in diagnosing and managing. Guskiewicz's 2001 study examined and compared the epidemiology of concussion among high school football athletes and collegiate football athletes. His study found an overall concussion rate of 5.1%.[2] Further studies

have found similar rates of concussion among football athletes. McCrea, in his study of neurocognitive effects following concussion, found a concussion rate of 3.8% among 2385 high school and football players.[3] In a later study of NCAA collegiate football players, McCrea discovered a concussion rate of 6.2%.[33]

Another method of estimating the impact of concussion is to divide the number of concussions by the amount of athlete exposures (AE). An athlete exposure is defined as one athlete participating in one practice or game. Marar found a total athlete exposure rate of .25 concussions per 1000 AE when including high school football, boy's and girl's soccer, boy's ice hockey, boy's wrestling, boy's and girl's basketball, baseball, softball, boy's and girl's lacrosse, girl's field hockey, gymnastics, cheerleading, swimming and diving, track and field, and girl's volleyball.[82] This number was supported by Gessel, who found a similar rate of .23 conc/1000 AE in nine high school sports.[90] Football rates of concussion per athlete exposure are higher. Guskiewicz, in his study of NCAA football, found a rate of .81 concussions per 1000 athlete exposures,[6] and in his study of both high school and collegiate football, he discovered a rate of .70.[2] It is interesting to compare the rates of concussions in gender comparable sports. Marar reports that males have a higher total rate of concussions per athlete exposure (.31) than females (.17), mainly because football does not have a comparable female sport. When only gender comparable sports (soccer, basketball, baseball and softball), are utilized, females take the lead, with a rate of .16 concussions per 1000 athlete exposures, well above the male rate of .10 per 1000 AE.[82] Covassin also discovered that female soccer athletes sustained concussions more frequently during games than male soccer players.[91] Several theories propose reasons for this gender discrepancy. It has been discovered that females are more likely to report concussion symptoms, as shown by Dick in his literature review of gender differences and concussion.[92] It is

also possible that females have a lower threshold for injury, or poorer neck and head biomechanics.[93] Tierney examined the head and neck biomechanics of males and females when a sudden, external force was applied. Males stiffened their neck and shoulder musculature, allowing their head, neck, and trunk to absorb the impact. Females demonstrated significantly less neck stiffness and isometric strength, allowing their head and neck to move to a greater strength.[94]

<div align="center">Concussion Reporting Rates</div>

It is difficult, however, to draw accurate conclusions from these numbers, when athletes are likely to not report concussive symptoms. McCrea conducted a survey of high school football players that informed them of common concussion symptoms and then asked whether they had ever experienced those symptoms. 15.3% of athletes claimed that they had indeed suffered headache, dizziness, balance issues or many other symptoms following a blow to the head. 52.7% of the athletes stated that they had not reported their injury. When asked why they had not reported their concussion, the most common answer (66.4%) was that they did not think it was serious enough to report. The second most common reason (41.0%) was that the athlete did not want to leave the game, and trailing close behind were the reasons that the athlete did not know that they had suffered a concussion (36.1%) and that they did not want to let down teammates (22.1%). Kaut reported that as many as 30 percent of athletes may play despite having a headache following a blow to the head. 20 percent of the high school athletes in his study reported being diagnosed with a concussion, but 30 percent reported having experienced symptoms of a potential concussion.[95] Many more concussions may be occurring than are being reported. In addition to managing the concussions that are reported, athletic trainers must also

concern themselves with recognizing the unreported brain injuries that athletes attempt to play through.[34]

Dose response

A grave danger to the concussed athlete is the concept of dose response. Guskiewicz, in his 2003 study of NCAA football players discovered that the athletes who sustained a single concussion were 1.5x times more likely to suffer a second concussion in the same season. Those who sustained a second concussion were 2.5x more likely to suffer a third, and following a third concussion, there may be a 3x greater likelihood to sustain an additional concussion.[6, 7] Zemper conducted a large-scale study of two consecutive seasons of high school and collegiate football programs. Football athletes who had a history of a prior concussion were at 6x greater risk to sustain a second concussion.[7] Harris demonstrated that the time between repeat visits to the emergency room (ER) for concussions decreases after each concussion.[96] For patients who were treated by the ER for more than one concussion, the time between the first and second concussion was, on average, 758 days. The average time between ER visits for a second and third concussion was 613 days, and the average time between a third and fourth concussion was 303 days.[96] In addition, Harris reported that those who were treated for a single concussion were 2.5x more likely to be treated for a second, and 6x more likely to be treated for a third.[96] Also, subsequent concussions have been demonstrated to be more severe and more debilitating.[26] Collins examined the presentations of athletes with and without a history of prior concussion. Those with a history of prior concussion were more likely to have a poor on-field presentation, were 7x more likely to present with loss of consciousness, 4x more likely to have post traumatic amnesia, and 4x more likely to demonstrate confusion or prolonged mental status change.[26]

Repeat concussions may leave the victim more damaged in the areas of EEG and postural control as demonstrated by Slobounov.[20, 29] In two studies, the participants returned to baseline in postural control and EEG at one month following their first concussion. However, following the second concussion, the participants still had severe deficits in both postural control and brain electrical activity, indicating that a single concussion may make an additional concussion more severe and require more time to recover.[26]

A history of three or more concussions has been linked to a variety of late life conditions. Guskiewicz et al, who surveyed retired NFL players and their families, discovered that those who reported a history of three or more concussions had an earlier onset of Alzheimer's, an increased risk of developing mild cognitive impairment, and were three times more likely to develop depression.[8, 9] A further late life peril of repeat concussion is that of Chronic Traumatic Encephalopathy (CTE). CTE was first diagnosed posthumously by Omalu, who dissected the brain of a retired professional football player, who died with symptoms of a mood disorders memory impairment, and Parkinson's. Within the brain was extensive damage in the form of neurofibrillary tangles and plaque.[97] This first modern case of CTE has been corroborated by studies by McKee, who examined the brains of 12 contact sport athletes. McKee's examination revealed extensive neurological damage in each brain. In a more recent study, McKee analysed the brains of 85 post-mortem subjects with histories of repetitive concussions. Evidence of CTE was found in 68 male subjects.[98] These studies have strengthened the theory that perhaps repetitive blows to the brain or repetitive concussions may produce cumulative damage to neurological structures.[11, 12]

Dose response can be reduced by clinicians through improving return to play policies. Guskiewicz and McCrae demonstrated that while it is true that each concussion an athlete suffers

leaves them more likely to sustain a second, the vast majority of these subsequent concussions occur within a window of 7-10 days.[6, 33] Giza contends that the diminished cerebral blood flow and associated metabolic crisis leaves the brain vulnerable for a period of 7-10 days,[73] which corresponds to the above findings. Based on this information, it would seem that removing athletes from competition for a period of at least 7-10 days would reduce up to 90% of repeat concussions. The 4th international consensus statement advises that no athlete should return to play when symptomatic, and athletes should return to play in a stepwise, progressive return to full contact participation.[99] Clinicians should follow these guidelines in order to reduce the amount repeat concussions and avoid the danger of dose response.

Concussion Evaluation

There are many difficulties in evaluating concussions. One challenge to clinicians is that athletes may not report a concussion, as discussed above. Another challenge is that concussion evaluation relies heavily on subjective information; obvious signs of balance deficits, loss of consciousness, or confusion are often absent.[32] The athlete may be able to play and behave normally. Thus, the clinician is placed in a difficult position of making decisions based largely on an athlete's self-reported symptoms. Imaging, such as computerized tomography or Magnetic Resonance Imaging (MRI) may help detect skull fractures or edema, but cannot diagnose a concussion.[99] A functional MRI may shed some light on the activation patterns of an injured brain, but functional MRI machines are expensive and rare. In order to aid clinicians in making accurate decisions, efforts have been made to objectify concussion evaluation, by creating numerous objective tools that attempt to measure changes in balance, neuropsychological performance, neurocognitive performance, or symptoms.

One of the most commonly used assessment tools is a symptom checklist.[100] The Graded

Symptom Checklist (GSC) asks athletes to report their symptoms and then rate how severe those

symptoms are. Signs and symptoms have been extensively studied. Headache is the most

common symptom to be reported by an injured athlete, as confirmed by Guskiewicz, Marar, and

Maddocks at rates of 86%, 94%, and 93%, respectively.[2, 76, 82] Dizziness is also commonly

reported (64-77%), as well as nausea (31-61%), cognitive difficulty (55-70%) and blurred vision

(75%).[6, 76, 82] The GSC has a criterion validity that may vary from .68 - .96 depending on each

item on the checklist.[58] The sensitivity of the GSC .04-.96 depending on the time of the

examination; it is less sensitive a week out when compared to immediately following

concussion.[57] The sensitivity of the GSC is 1.00.[57]

Loss of consciousness was once considered a hallmark sign of concussion, as evidenced by

earlier rating scales such as AAN and the Colorado Medical Society.[101] However, loss of

consciousness is a rare in concussion, as the rate of loss of consciousness ranges from 5-8%.[3, 6, 33]

Collins discovered that experiencing loss of consciousness did not help predict the severity of

concussion.[26] Experiencing post traumatic amnesia as a symptom leaves you 4.2x more likely to

have a poor outcome in concussion, and retrograde amnesia indicates a 10x greater risk of poor

outcome following concussion.[102] Previous grading systems were based almost exclusively upon

the notion that loss of consciousness indicates greater severity of concussion.[101] Several studies

suggest that perhaps post-traumatic amnesia may be more indicative of concussion severity.[102, 103] Therefore, the new Cantu-revised grading scale includes both post-traumatic amnesia and loss

of consciousness as grading criteria.[101]

Another commonly utilized tool is the Standardized Assessment of Concussion. The SAC was

studied by McCrae and was found to have 95% sensitivity and 76% specificity to concussion

when used on the sideline immediately after injury.[104] For a sample of football players, there was an average baseline of score 24 and an average drop 4-6 points following the injury.[3] Unfortunately, the SAC suffers from a severe practice effect – the average was above baseline within 48 hours, even when the sample remained symptomatic.[3]

Balance tests are another method of identifying deficits caused by concussion. The Sensory Organization Test has been used frequently in concussion research, but it requires expensive equipment and so is not available for use by most clinicians. The BESS test is a much more practical option. The only equipment required is a foam pad, and the test can be quickly administered. The reliability of the BESS test has been studied several times; Finnoff used three clinicians to determine the intrarater and interrater reliability of the BESS test. The total intrarater reliability was .74 and the total interrater reliability was .57. Good reliability is defined as .75 or above. The minimum detectable change is 7.4, meaning that there will have to be at least an 8 point difference between scores in order to conclude that there is an actual difference that cannot be attributed to error.[81] Hunt completed a study that examined the reliability of the BESS and then proposed a new method that may aid in improving the BESS's reliability. The double leg stances have been consistently shown to be unreliable because of the low amounts of errors. Hunt et al suggest omitting these stances and adding two extra trials. When using this new modified BESS, the researchers achieved a reliability of .88.[80] Overall, Bell, in a literature review on the BESS, reported that the BESS has moderate to good reliability.[105]

Computer based neuropsychological examinations are a popular means of diagnosing concussion and evaluating readiness to return to play.[100] Tests such as Headminder and ImPACT have been used at high schools and colleges by clinicians to aid in the diagnosis and evaluation of concussion. However, Register-Mihalik and Broglio have shown that computer based testing

does not have sufficient sensitivity to serve as the one and only tool used for evaluation and examination. Register-Mihalik demonstrated that computer based neuropsychological exams only have 50% sensitivity at best, and Broglio contends in his study of the concussion assessment battery that ImPACT, when excluding the symptom checklist, only has 62.5% sensitivity.[14, 106] Computer-based neuropsychological exams are a useful tool, but cannot serve as the cornerstone of concussion evaluation.[99]

Broglio et al discovered that while no concussion assessment tool possesses a sensitivity higher than 70%, when neuropsychological, neurocognitive, symptom checklists, and balance are all combined, the sensitivity achieves 89-96%. This article underscores the importance of using a concussion assessment battery rather than any single concussion assessment method.[14] Concussion evaluation has improved in the sport setting, because athletic trainers are more aware of concussion signs and symptoms and the utilization of tools such as the SAC, BESS and neuropsychological exams have greatly increased.[78, 79, 100] In addition, athletic trainers have improved in their knowledge of how to manage concussion.[78, 79, 100] 30% of athletes were returned to play the same day in 2002,[2] but, ten years later, that number has plummeted to 2%.[82]

Unfortunately, the practice effect of standard concussion assessment procedures has been well documented. In McCrea's 2002 article, the SAC test was used to immediately test concussed athletes and then retest them at fifteen minutes, forty eight hours and ninety days.[3] Overall, the athletes in the study showed immediate, significant declines in their SAC scores. However, these scores were near baseline at fifteen minutes following concussion and were above baseline at forty eight hours following injury. It is unlikely that the population was recovered two days following concussion, and further unlikely that somehow the concussive blow helped them achieve higher neurocognitive function. The reasonable explanation is that there is a significant

practice effect, and therefore the SAC is not very helpful in determining recovery from concussion.[3] Neuropsychological computer exams demonstrate a practice effect as well. Lovell examined 42 athletes with mild concussions, and overall, the sample's neuropsychological scores in reaction time, memory composite, and processing speed all improved.[32] In Broglio's study of asymptomatic athletes, concussed individuals demonstrated improved improved ImPACT scores on every aspect of the exam.[24] BESS scores are known to improve dramatically over repeated administrations of the test. Gysland's 2011 study on subconcussive blows in collegiate football showed that, on average, the sample improved by almost 6 points in their BESS scores over a competitive season.[15] Valovich also demonstrated a significant practice effect when using the BESS in the assessment of healthy young athletes across the five testing sessions. On day 5, 7, and 60, the participants committed 2-3 fewer errors than on their baseline exam.[107] A striking example of the practice effect of the assessment battery is found in McCrea's 2003 study of 94 concussed NCAA football athletes. In cognitive assessment, the athletes performed a full point better than their baseline performance on day 7 and in postural assessment, the concussed cohort performed 4 less errors than they had at baseline.[33] Either concussion improves the postural, neuropsychological and neurocognitive performance of athletes in each of the above examples, or there is a practice effect that may mask the true length of recovery.

Can symptom resolution help determine concussion recovery? Many studies suggest that symptom resolution does not correlate well with recovery from concussion. One reason for this is that symptom resolution is not equivalent to recovery. Symptoms and other deficits caused by concussion recover independently. McCrae, in his study of NCAA football demonstrated that recovery from concussion usually takes from 5-7 days. Neurocognitive function recovers in 5-7 days, neuropsychological function requires 2-7 days to return to baseline, and balance generally

is restored in from 3 to 5 days.[33] Because symptoms return to baseline at a different rate than other areas of recover, clinicians cannot safely assume that the presence and absence of symptoms determines recovery. In addition, impairments have been frequently demonstrated in asymptomatic athletes. Broglio studied twenty one NCAA division one athletes. These athletes were baseline tested with ImPACT, tested following their concussion, and then retested the first day that they reported being asymptomatic. Broglio found that in 38% of his participants, neuropsychological deficits persisted even though the athletes had reported that they were asymptomatic. This may be explained, in part by athletes frequently underreporting their symptoms due to lack of knowledge or a pressure to continue to play.[34, 95]

Concussion Recovery

The effects of concussion have been shown by Slobounov to linger past symptom resolution. Three of Slobounov's studies will be discussed. In the first, he measured the EEG-IQ (the complexity of brain signals) of 20 concussed individuals and then re-measured them up to 30 days following the injury. All of the concussed athletes showed a decrease in the complexity of their brain wave signals immediately following concussion. From that point, the athletes showed a typical checkmark response, in which scores immediately plunged, then gradually returned to baseline. The surprising finding of this article is that the check mark response took thirty days on average to return to baseline, even though no athlete reported a symptom past 10 days.[20] Slobounov's second study used force plates to measure the participant's balance and virtual reality to perturb the participant's vision. In this second study, deficits in balance were noted 30 days out. In this study, like the previous one, symptoms were not reported past 10 days.[29] In another Slobounov study, 380 college aged athletes were baseline tested. The baseline testing

included neuropsychological testing, EEG measuring, and a center of pressure measurement. 49 subjects suffered a concussion, and though none of them reported symptoms after day 7, they were remeasured five times within the next year. This study demonstrated postural issues that persisted beyond day 30, and also demonstrated changes in the EEG of the brain that did not return to baseline until 12 months post injury.[22]

Other authors support Slobounov. Gao also examined the effect of concussion on center of pressure, and discovered that deficits that persisted beyond 10 days. In Gao's study, 10 concussed athletes were each asked to stand on a force plate for two minutes. During this static stance test, the athlete's center of pressure was measured. Each athlete was examined daily following concussion. The results show that the center of pressure shows increased entropy, or randomness, following concussion. This randomness is greatest on day 1 following concussion, but not every participant was resolved prior to day 10 (when the first subjects returned to play).[19] It is logical to conclude from the above research that since neuropsychological, balance and brain wave deficiencies may persist beyond symptom resolution, that symptom resolution is not an adequate measure to determine return to play.[24]

Evaluation and initial management of concussion may have greatly improved, but there is still a lack of a method of ascertaining recovery from concussion. Athletic trainers can identify a concussion with 89-96% accuracy,[14] and research indicates a 7-10 day window of vulnerability,[6] but athletic trainers still have no gold standard of determining recovery from concussion, and thus when to return to play. Current standards of practice dictates that athletes be returned to participation based on their return to baseline on neuropsychological, cognitive and balance tests, and upon the resolution of their symptoms.[108, 109] While this is certainly an improvement over previous years, in which 30% of athletes were returned to play the same day in Gusckiewicz's

2002 study, there is still much room for improvement.[7] Practice effects likely make neuropsychological, neurocognitive and balance tests inadequate methods of tracking recovery and symptoms do not necessarily coincide with recovery. Sophisticated equipment that requires extensive analysis may be able to detect lingering deficits, but few clinicians will have access to such equipment. Clinicians need an instrument that will be challenging enough to identify minor deficiencies. Deficits in visual motor performance following concussion have been documented, and may be sensitive to the long-term effects of concussion.[5, 66, 110-112]

<center>Visual Reaction Time</center>

The initial impetus for a planned movement comes from subcortical and cortical regions of the brain, which create an initial drive for a motion to be carried out. The plan for this movement is refined in the basal ganglia and cerebellum and then relayed through the thalamus to the motor cortex. From the motor cortex, the spinal cord carries the message for the movement to the specific motor units required for the movement.

An important tool in the evaluation of concussion is reaction time, the amount of time between the onset of a stimulus and the initiation of a response. Movement time is the time required for the body to complete the desired response, and response time is reaction and movement time combined.[113, 114] Simple reaction time uses a single stimulus and a single response. Visual reaction time, the reaction to a visual stimulus, has been shown to require about 140 – 270 ms.[41, 59, 115-118] Hick's law dictates that reaction time will increase as the number of possible responses increases.[119] Fitt's law is also important in the study of reaction time and movement time. In reaching movements, increased velocity will result in decreased accuracy and increased accuracy will come at the cost of increased speed.[120] In reaching movements, reaction

<center>56</center>

time consists of the time required for the central nervous system to plan the direction and magnitude of the arm movement in response to the target location.[62, 114] When reaction time is measured through rapid, aimed arm movements, several authors contend that the participant will engage a rapid, sub-cortical visual motor pathway to achieve very low reaction times.[41, 118, 121-125] This rapid pathway may transmit sensory information from the retina to the superior colliculus, and then either directly to motor centers, or to the posterior parietal cortex, which plays an important executive role over reaching movements.[35, 41, 43]

Reaction time is often impaired following concussion, and is commonly used as an assessment tool, using computer based neuropsychological exams to aid in the diagnosis of concussion.[126, 127] Reaction time has also been used as a stand-alone clinical measurement following concussion.[59, 117] Most studies have shown an initial increase in the reaction time of concussed population, which usually recovers within 1-2 weeks.[4, 17, 30, 32, 102] However, while assessments of reaction time or visual motor speed may be able to identify the initial effects of a brain injury, these measures return to baseline within 1-2 weeks, while more sophisticated analysis of motor function is able to identify deficits for one to one year following the concussion.[4, 17, 30, 44, 128]

Oculomotor Visual Motor Coordination

The eye is the visual sense organ of the human body and its purpose is to receive light from the environment and transmit visual information to the brain.[129] The lens of the eye bends light rays to form an inverted image on the posterior aspect of the eye, known as the retina.[130] The retina is tissue made of light-sensitive cells which translates the light into neural signals.[129, 131] These light sensitive cells are known as rods and cones. Cones detect color and detail, while rods are sensitive to light and motion.[129] The center of the retina, known as the fovea, contains the

highest concentration of photoreceptors (primarily cones), and thus provides the highest visual acuity. The human fovea only supplies this high acuity for two to three degrees of the visual field.[129, 131] In order to provide the highest level of definition for an object that requires attention, the eye must move to bring the object in line with the fovea.[129, 130]

Each eye is surrounded by six muscles, the inferior and superior oblique, and the lateral, medial, superior and inferior rectus, which are responsible for rotating the eyeball within the orbit.[129] These muscles, innervated by the oculomotor, trochlear, and abducens nerves, provide several types of eye movements, including saccades, pursuit tracking, and vergence.[37, 129] Saccades are planned, rapid movements of the eye which can bring an object into the focus of the fovea, known as foveation. Pursuit tracking allows the eye to follow a moving object.[129, 130] Vergence tracks objects that move closer to or farther from the eyes by narrowing or widening the angle of sight of the eyes.[132]

The movement of the eyeball is guided by the visual information provided by the eye through a feedback mechanism. Visually-guided control of the extraocular muscles is directed through a neurological pathway leading from the retina to the superior colliculus and then to the oculomotor nerve.[41, 42] This direct pathway allows for extremely rapid saccade reaction times.[41, 133] The ability to control and orient the eyes is crucial both to athletic performance and everyday life, and deficits in oculomotor function have been repeatedly found in those whose brains have been injured.[37, 129, 132, 134-136]

Several authors have examined the link between oculomotor dysfunction and mild traumatic brain injury.[5, 44, 48, 49, 137, 138] The smooth pursuit component of oculomotor function may be impaired following concussion. Heitger et al have conducted a series of studies, comparing mTBI patients with healthy controls using measurements of oculomotor and upper limb visual

motor function.[5, 44, 48, 49, 139] In the first study, acutely concussed patients had increased latencies during memory guided saccades, increased saccadic directional errors, and increased lag during smooth pursuit tasks. The authors suggested that these deficits may be due to the effect of concussion, either by direct injury or diffuse axonal injury, on the frontal eye field, the dorsal lateral prefrontal cortex, and the posterior parietal cortex.[5] In a follow up study, patients had saccadic latencies and diminished saccadic accuracy that lasted up to three months post-concussion.[44] Performance on oculomotor tests 1 week following concussion effectively predicted recovery at three and six months and post-concussion syndrome patients have demonstrated abnormalities in anti-saccades, self-paced saccades, smooth pursuit.[48, 49]

Suh et al conducted two studies to examine predictive eye movements, movements that estimate the trajectory of a moving object, and smooth pursuit eye movements in concussed patients.[137, 138] In the first study, the participants, at an average of 1.6 years following their initial concussion, had a decreased ability to accurately track a moving object with their eyes.[137] In the follow up study, similar deficits were found during a target blanking task, in which a moving target is briefly blanked out, and then resumes movement. The participants must follow the target with their eyes, and predict where the target will be following the brief lapse in vision. The concussed participants demonstrated more error variability during this task, even though most participants (20 of 26) were between 6 weeks to 2 years post-concussion.[138] Ciuffreda et al retrospectively examined the medical records of 160 mTBI patients. They discovered that 90% of the participants had an oculomotor dysfunction following the concussion, with a vergence abnormality being the most common.[140] Several other studies have examined oculomotor dysfunction in a military setting and have discovered that as many as 50-70% of participants suffering from a concussion may have associated oculomotor injury, while only 20-30% of

young adults in the general population suffer from oculomotor dysfunction (Porcar 1997, Goodrich 2007, Lew 2007, Stelmack 2009, Brahm 2009, Thiagarajan 2011).[141-145] Concussions appear to lead to oculomotor deficits both acutely and years following concussions in military, athletic and civilian populations (Suh, Heitger, Thiagarajan, Ciuffreda).[44, 132, 138, 140] The examination of oculomotor function appears to be an effective means of assessing those suffering from concussion, but, unfortunately, the complexity of the analysis of eye movements and a lack of baseline or normative data restricts its usefulness in the clinical setting.

<div align="center">Visual Motor Coordination</div>

Visual motor control is the use of visual perception to guide and direct movement.[36, 120] Visual motor control involves the collection of visual information from the eyes, the interpretation and organization of this information in the posterior reach region of the posterior parietal cortex, and then the use of this information to produce an efferent response.[37] This is a very complex process that involves many neurological pathways and areas of the brain, including the cerebellum, cortical and subcortical structures.[40, 129] Due to the complexity of this function, it is thought to be easily disrupted by brain injury.[5]

Visual motor coordination of the upper limb may be inhibited following concussion. Heitger was the first to examine upper limb movement in concussed participants. He used several examinations that required 30 recently concussed participants to quickly and accurately move a steering wheel, which controlled a cursor on a monitor. When compared to the group of healthy control participants, the concussed subjects demonstrated lower peak arm velocity 2-9 days following concussion.[5] In a follow up study, Heitger used identical test procedures to test a population of 37 recently concussed participants at one week, 3, 6, and 12 months post injury.

His population suffered from post-concussion syndrome, and 60% of the participants were symptomatic at the 12 month follow-up. He discovered prolonged deficits in upper limb accuracy and velocity that persisted up to one year following concussion.[44] Heitger used the same population and methods in a follow up study to try and predict overall recovery from concussion at 3-6 months postinjury. He measured recovery at 3-6 months using self-reported health status and psychometric testing. When the measures of arm visual motor coordination and saccade testing were combined, it accounted for 70-89% of the variance in recovery.[49] Locklin tested a sample of 10 athletes with a history of concussion on a visual motor task that required athletes to accurately touch a randomly occurring image on a screen. 7 of the 10 experimental participants had not sustained a concussion for over 7 months prior. There were no significant group differences, but a trend towards significance for a main effect of group on response time.[66] The assessment of visual motor coordination in concussed athletes has not been extensively studied, but may provide a useful means of tracking recovery. More research should be conducted to examine the potential benefits of a using a visual motor task to assess for deficits following concussion.

Dynavision System

The Dynavision is a device that is used by professional athletes, the military, physical therapists, athletic trainers and strength and conditioning coaches to train and assess visual motor coordination.[50, 146, 147] It is a large black board that is 135 cm wide and 167-243 cm tall. It rests on a mount that can adjust for individuals of varying height. In the center of the front of the board rests a small LED screen. 64 lights surround the central screen in 5 concentric circles. To use the dynavision, one would stand in front of the rectangle and stare at the center screen,

positioned 10-20 cm from the screen. As the lights randomly light up, the individual who is being tested is tasked with reaching out as quickly as possible and touching the lights to turn them off. This requires the individual to rely on his visual motor coordination to accurately and quickly hit the targets.[50] A standard exam on the Dynavision is the A* exam, which requires the participant to extinguish as many lights as possible within 60 seconds. The score that is recorded is the number of lights that the participant correctly hits within the time period.[148]

The Dynavision system has been studied for its reliability by Klavora. In his study of the Dynavision's test retest reliability, he found a correlation coefficient of .88-.97 for the A* exam.[52] Wells also examined the reliability of the dynavision system and discovered that the ICC for the A* exam is .75. Vesia compared the performance of participants on the simple task to performance on a battery of standard visual motor tests. The study demonstrated that dynavision scores correlate moderately well, .42-.75., with scores on the conventional tests.[50]

Visuomotor testing may be sensitive to the lingering deficits of concussion. The Dynavision should be researched as a potential tool for evaluating recovery from concussion. The Dynavision system may be challenging enough to be sensitive to the lingering deficits seen in concussed athletes. If it could indeed measure these deficits, then it would be a terrific benefit to clinicians and researchers who want to return athletes to play in the safest manner possible. Research should be conducted to determine the effectiveness of the dynavision as a method to measure recovery.

APPENDIX C
IRB, TABLES AND FIGURES

	Georgia Southern University Office of Research Services & Sponsored Programs	
	Institutional Review Board (IRB)	
Phone: 912-478-0843		Veazey Hall 2021 P.O. Box 8005
Fax: 912-478-0719	IRB@GeorgiaSouthern.edu	Statesboro, GA 30460

To: Erik W. Sanders
Dr. Thomas Buckley
Dr. Horace Deal
Dr. Jody Langdon
Dr. Barry Munkasy

CC: Charles E. Patterson
Vice President for Research and Dean of the Graduate College

From: Office of Research Services and Sponsored Programs
Administrative Support Office for Research Oversight Committees
(IACUC/IBC/IRB)

Initial Approval Date: 8/7/13

Expiration Date: 7/31/14

Subject: Status of Application for Approval to Utilize Human Subjects in Research

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After a review of your proposed research project numbered **H14010** and titled **"The Use of a Visual Motor Test to Identify Lingering Deficits in Concussed Collegiate Athletes,"** it appears that (1) the research subjects are at minimal risk, (2) appropriate safeguards are planned, and (3) the research activities involve only procedures which are allowable. You are authorized to enroll up to a maximum of **60** subjects.

The purpose of this study is to determine if a visual motor test can identify lingering deficits in college students with concussions.

Therefore, as authorized in the Federal Policy for the Protection of Human Subjects, I am pleased to notify you that the Institutional Review Board has approved your proposed research.

If at the end of this approval period there have been no changes to the research protocol; you may request an extension of the approval period. Total project approval on this application may not exceed 36 months. If additional time is required, a new application may be submitted for continuing work. In the interim, please provide the IRB with any information concerning any significant adverse event, **whether or not it is believed to be related to the study**, within five working days of the event. In addition, if a change or modification of the approved methodology becomes necessary, you must notify the IRB Coordinator **prior** to initiating any such changes or modifications. At that time, an amended application for IRB approval may be submitted. Upon completion of your data collection, you are required to complete a *Research Study Termination* form to notify the IRB Coordinator, so your file may be closed.
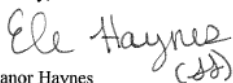
Sincerely,

Eleanor Haynes
Compliance Officer

Table 1. The demographic information for the concussion and control groups.

	Number	Sport	Age (yrs)	Height (cm)	Weight (kg)	Conc Hx	Time Lag (days)
Conc	**13** (6 Male)	**5** CHL, **4** FB, **1** WBX, **1** MSC, **1** VB, **1** SWM	18.8 ± 0.72	174.7 ± 12.2	75.5 ± 23.2	0.38 ± 0.77	22.8 ± 3.5
Ctrl	**13** (6 Male)	**5** CHL, **4** FB, **1** WBX, **1** MSC, **1** VB, **1** SWM	19.3 ± 1.1	173.5 ± 11.9	75.8 ± 19.9	0.31 ± 0.48	23.2 ± 3.7

Table 2. The GSC scores for concussion and control groups before and after T1 and T2.

	Conc T1	Conc T2	Ctrl T1	Ctrl T2
Pre	1.23 (± 3.9)	0.0	0.08 (± .28)	1.7 (± 5.5)
Post	0.9 (± 2.5)	0.0	0.0	1.5 (± 5.0)

Table 3. The *p* value, degrees of freedom, *F* value, eta squared and observed power for the significant findings of the 2x2 (group x session) repeated measures ANOVA's for each dependent variable.

DV	Result	*p*-value	Degrees of Freedom	*F*-value	η^2	Observed Power
A Score	Main effect for session	p≤.001	24	38.1	.61	1.0
UL	Main effect for session	p≤.01	24	8.4	.26	.79
UR	Main effect for session	p≤.01	24	12.9	.35	.93
LL	Main effect for session	p≤.001	24	20.6	.46	.99
LR	Main effect for session	p≤.001	24	30.3	.56	1.0
RT	Main effect for session	p≤.05	22	4.9	.18	.56
MT	No significant findings					

Table 4. The mean (± SD) of each dependent variable for the concussion and control groups at T1 and T2.

	Conc T1	Conc T2	Ctrl T1	Ctrl T2
A* Score	76.8 ± 8.5	82.6 ± 10.9***	75.8 ± 12.4	82.7 ± 11.6***
UL (s)	0.77 ± 0.10	0.75 ± 0.10**	0.79 ± 0.13	0.75 ± 0.10**
UR (s)	0.74 ± 0.10	0.70 ± 0.10**	0.79 ± 0.13	0.72 ± 0.10**
LL (s)	0.81 ± 0.10	0.74 ± 0.12***	0.81 ± 0.14	0.74 ± 0.10***
LR (s)	0.80 ± 0.09	0.72 ± 0.11***	0.81 ± 0.17	0.71 ± 0.09***
RT (s)	0.32 ± 0.05	0.29 ± 0.05*	0.30 ± 0.04	0.29 ± 0.04*
MT (s)	0.24 ± 0.09	0.25 ± 0.03	0.26 ± 0.08	0.24 ± 0.06

* = main effect for session, $p<.05$

** = main effect for session, $p<.01$

*** = main effect for session, $p<.001$

Figure1. The Health Hx survey used to screen participants prior to participation in this study.
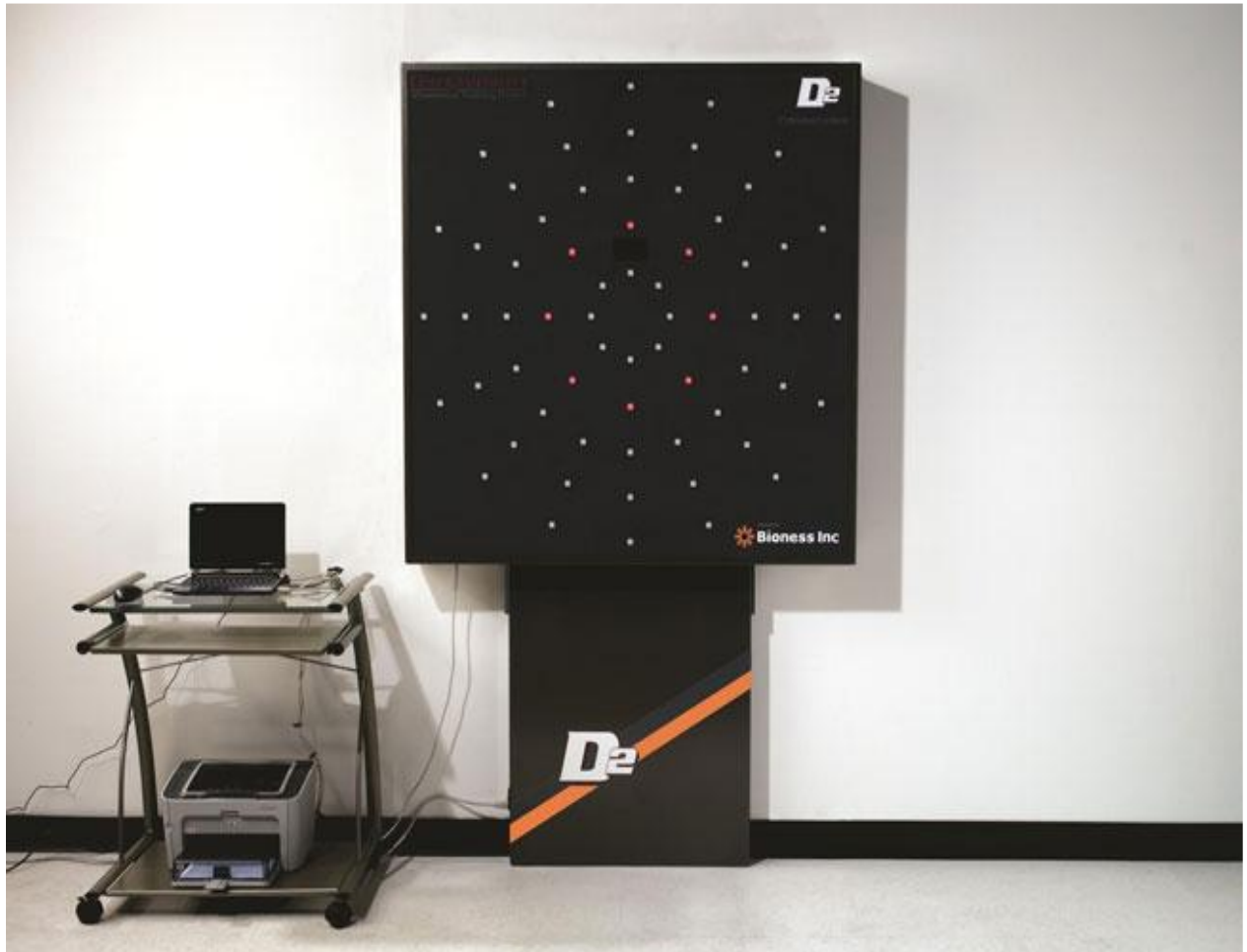
Figure 2. The Dynavision apparatus.

Figure 3. The Graded Symptom Checklist used to screen participants before and after each testing session.

How do you feel?

"You should score yourself on the following symptoms, based on how you feel now".

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6

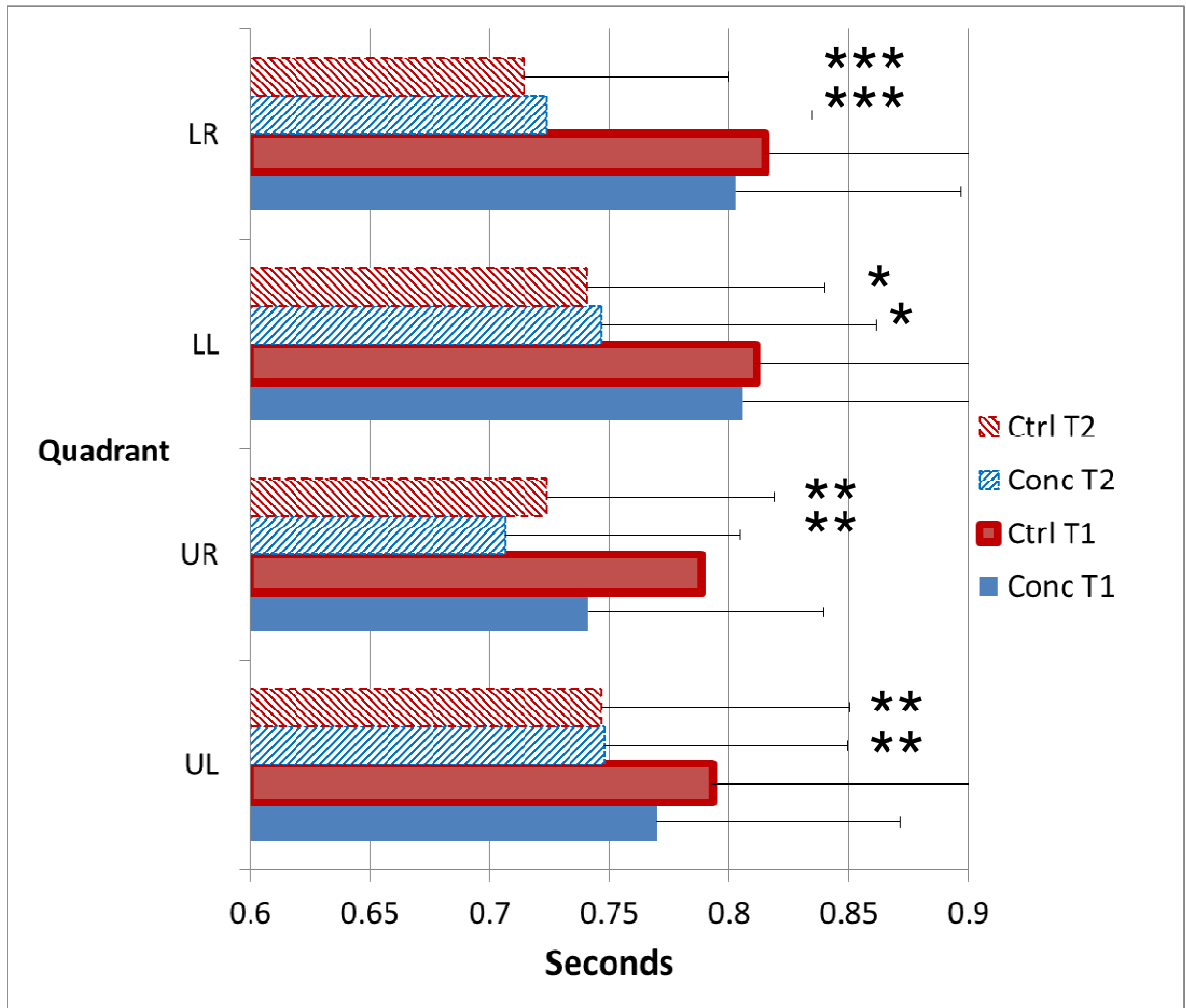**Total number of symptoms** (Maximum possible 22)

Symptom severity score (Maximum possible 132)

Figure 4. Mean A* score for the concussion and control groups across T1 and T2.
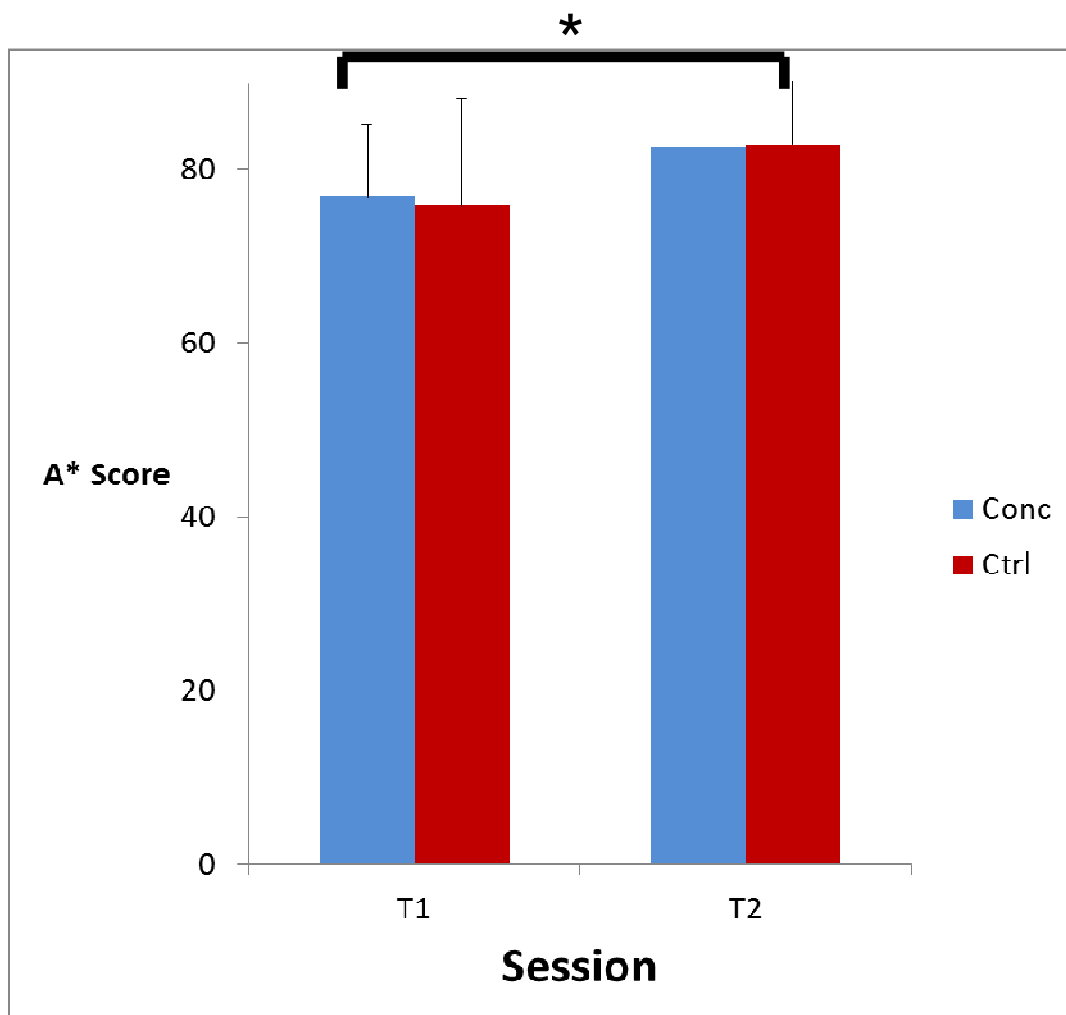
* = Main effect for session *p*≤.001

Figure 5. Response times for the UL, UR, LL, and LR quadrants during the A* exam for the concussion and control groups across T1 and T2.
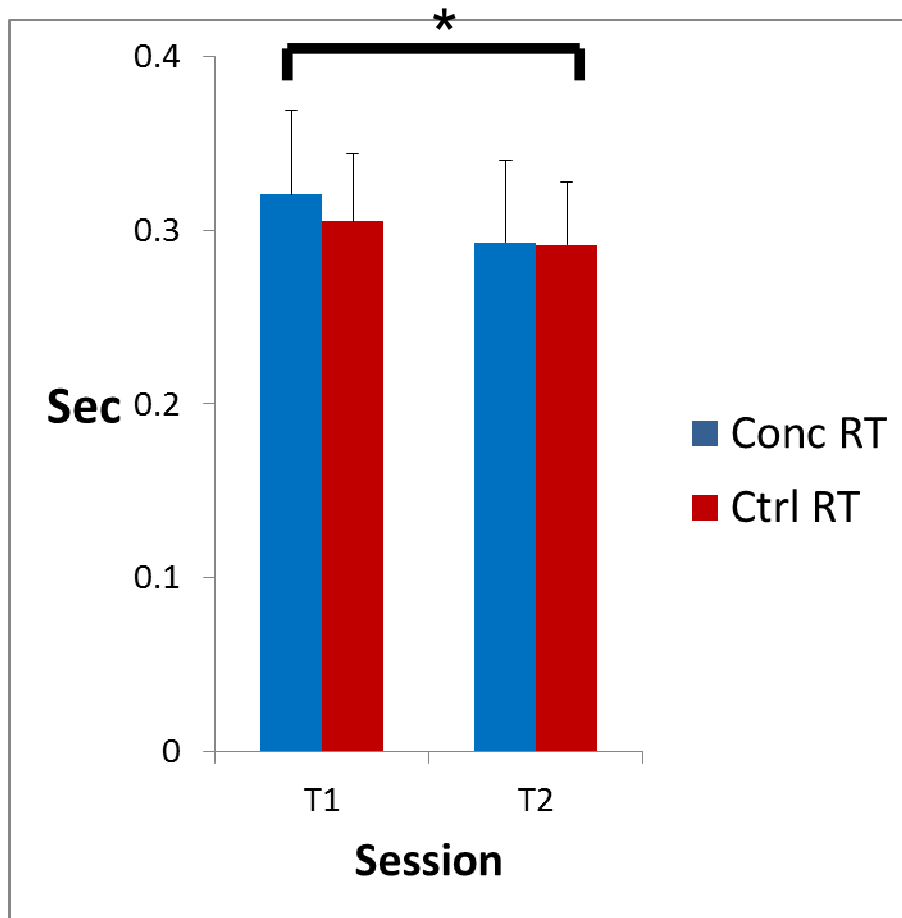
* = Main effect for session, $p \leq .05$

** = Main effect for session, $p \leq .01$

*** = Main effect for session, $p \leq .001$

Figure 6. Reaction time during the SVRT test for the concussion and control groups across T1 and T2.

* = Main effect for session (*p≤*.05)

Figure 7. Movement time during the SVRT test for the concussion and control groups during T1 and T2.
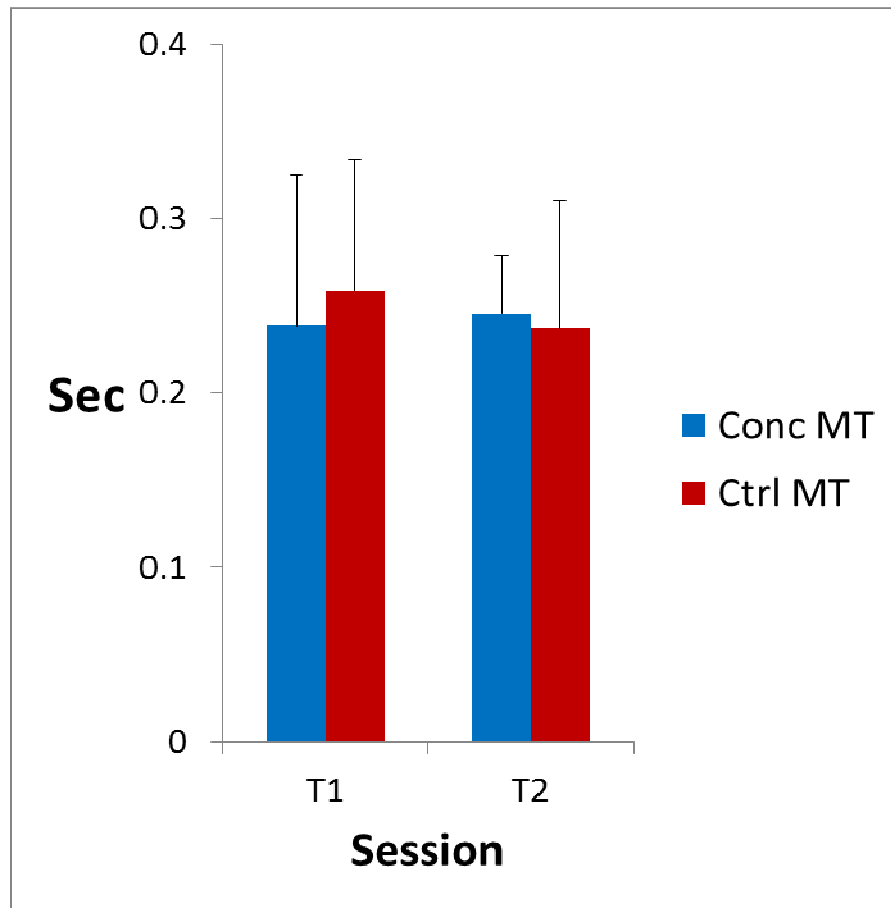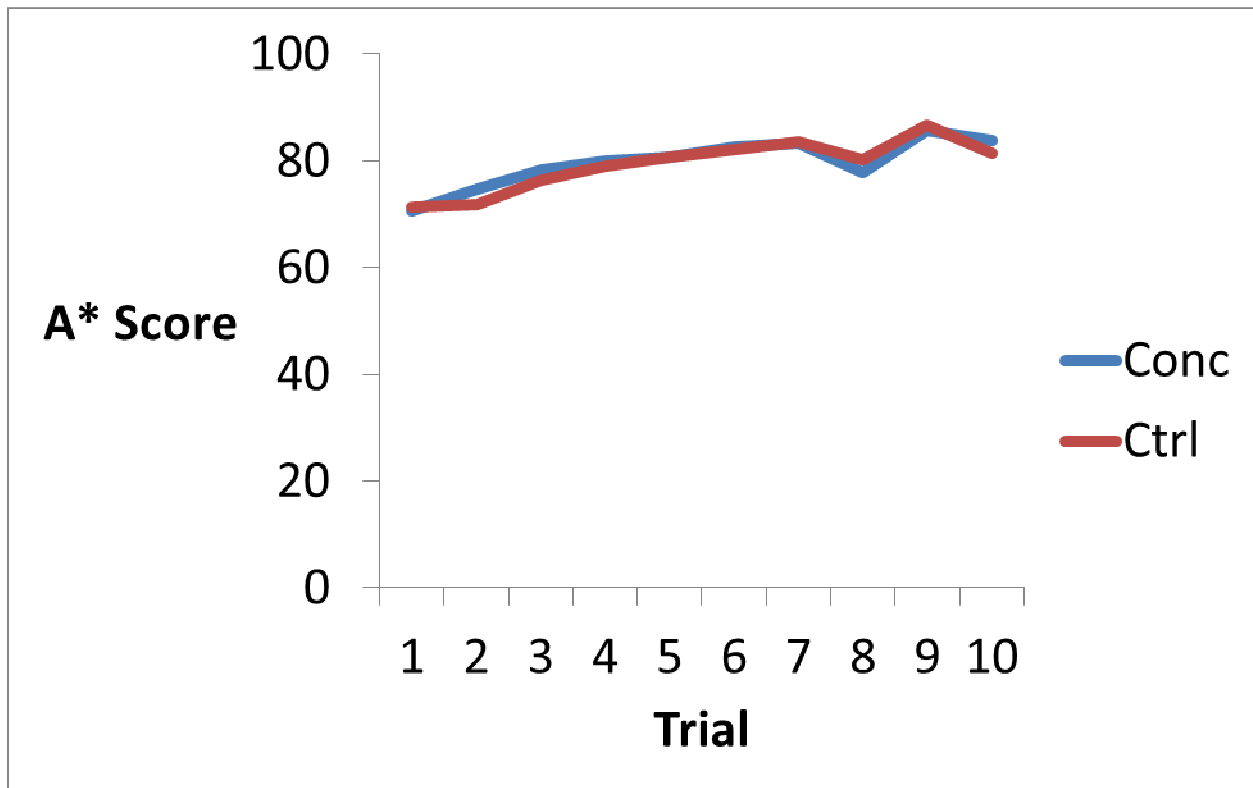
Figure 8. The average A* score for the concussion and control groups across the 10 trials (composed of trials 1-5 during T1 and trials 6-10 during T2).

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