Summer 2013

Choice Response Time Differences between Recently Recovered Concussed and Healthy Student-Athletes

Tiffen Tapia-Lovler

CHOICE RESPONSE TIME DIFFERENCES BETWEEN RECENTLY RECOVERED CONCUSSED AND HEALTHY STUDENT-ATHLETES

by

TIFFEN GABRIEL TAPIA-LOVLER

(Under the Direction of Barry Munkasy)

ABSTRACT

Some 1.6 to 3.8 million sports-related concussions occur annually in the United States. Utilization of test batteries and exercise protocols are recommended to ensure athletes recover completely. Many batteries involve response time (RT) tests, which show response time increases post concussion. A major limitation of RT tests is that all are done in static position. Additionally, many studies show a lingering effect on RT. The addition of RT tests to check for lingering symptoms could be beneficial. The purpose of this study was to see if significant differences could be found in RT tests involving dynamic movement between healthy student-athletes and those recently recovered from a concussion. Sixteen student athletes from a major southeastern university were recruited; half were healthy student-athletes (HSA), and half were recently recovered student-athletes (RRSA) from a concussion. Both groups were tested on two random choice response time tasks with dynamic movement using Quickboard (LLC, Memphis, TN). The first task, a delayed choice response time task was done with a 3-5 s delay after each stimulus; the second task was a continuous choice response time task. There were no significant differences between the two groups for either test. In the delayed choice response time task, ($U=31$, $p=0.916$), RRSA mean time was 0.68 ± 0.067 s; HSA mean time was 0.70 ± 0.068 s. In the continuous choice response time task ($U=25$, $p=0.401$), RRSA mean time was 21.63 ± 2.46 s and HSA mean time was 20.86 ± 2.92 s. There were no errors in the delayed choice response time task. Errors were made in the continuous choice response time task, but with no significant differences ($U=27$, $p=0.765$). RRSA mean error rate was 0.75 ± 1.43 s; HSA mean error rate was 0.875 ± 0.99 s. This study tested RRSA when deemed fully recovered. One reason RT may be similar is that university officials didn't allow RRSA to be tested until recovered, therefore response times could have recovered. Previous studies were done within a week of their concussions. Another reason was the low statistical power. It's possible a larger sample size could lead to a statistical difference.

INDEX WORDS: Response time, Student-athlete, Concussion, Return-to-play, Quickboard

CHOICE RESPONSE TIME DIFFERENCES BETWEEN RECENTLY RECOVERED CONCUSSED AND HEALTHY STUDENT-ATHLETES

by

TIFFEN GABRIEL TAPIA-LOVLER

B.S., Brevard College, 2011

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial

Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

STATESBORO, GEORGIA

2013

CHOICE RESPONSE TIME DIFFERENCES BETWEEN RECENTLY RECOVERED CONCUSSED AND HEALTHY STUDENT-ATHLETES

by

TIFFEN GABRIEL TAPIA-LOVLER

Major Professor: Barry Munkasy
Committee: Tom Buckley
Brandon Harris
Daniel Czech

Electronic Version Approved:
July 2013

ACKNOWLEDGMENTS

I would like to acknowledge all of the members of my committee. Dr. Munkasy for his patience and leadership in the writing of this thesis. Dr. Buckley for helping me understand that concussions are bad; Dr. Harris for helping me understand the statistical world a bit more. Dr. Czech for helping me keep a positive attitude through all of this. I would like to thank the athletic training staff and others for the recruitment of participants. And last, but not least my mother who has been very supportive of my studies.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

Concussions are a complex pathophysiological process affecting the brain, that are caused by traumatic biomechanical forces (McCrory, Meeuwisse, ..., & Cantu, 2009). It is estimated that 1.6 to 3.8 million sports-related concussions occur each year in the United States making this a major sports medicine health problem (Langlois, Rutland-Brown, & Wald, 2006).When an athlete has suffered a concussion, the homeostasis of the brain is disturbed. As a result, the brain will go through a series of physiological and metabolic changes in an attempt to recover (Giza & Hoyda, 2001). This may manifest itself by one or more symptoms. Some of the most commonly reported symptoms are blurred vision, fatigue, headaches, sensitivity to light and sound, poor concentration, poor balance, and poor response time (Eckner & Kutcher, 2010). In 80 to 90 percent of concussion cases, symptoms typically clear in seven to ten days (McCrea & Guskiewicz, 2003; McCrea et al., 2009; McCrory, Meeuwisse, Aubry, Cantu, & Dvorak, 2013).

There are no universally accepted methods to determine when an athlete has sufficiently recovered from a concussion and can return to play (McCrory, et al., 2013). However, by using a battery of tests that monitor recovery status, significant improvements have been made in making that determination (McCrory, et al., 2013). These test batteries are multifaceted and include the use of multiple tests such as computerized neuropsychological testing, cognitive screening, checking for common concussion symptoms, and testing impairment in balance (Broglio, Macciocchi, & Ferrara, 2007b; McCrory, et al., 2013). Additionally, many institutions have recommended use of a stepwise return-to-play exercise protocol (McCrory, et al., 2009; McCrory, et al., 2013). In this protocol, the athlete begins with light aerobic exercises that progress in intensity when the athlete is asymptomatic. The next step in the protocol is to perform sport-specific exercises, followed by noncontact practices, eventually leading to a return to full active participation. As long as the student-athlete remains asymptomatic, they can continue on to the next step. While most institutions and sport leagues have guidelines on using concussion test batteries, exercise protocols, and making safe return-to-play decisions, they differ on the specifics. Thus athletes in different institutions will be subject to different amounts of rest and return-to-play criteria.

Nearly all concussion test batteries are done in a seated and/or static position, limiting exposure to the types of dynamic and complex movements an athlete experiences on the field. The exercise stepwise protocols are the most physically demanding of the tests; however their main function is to ensure the athlete is asymptomatic during exercise and does not test for performance (Johnston et al., 2004; McCrory, et al., 2009; McCrory, et al., 2013). This could lead to problems since it remains uncertain how an athlete will be able to function on the athletic field and whether s/he would be able to perform the necessary dynamic movement accurately and quickly. A major concern is the possibility that many student-athletes are returning to the field too early and are in fact not fully recovered from their concussion. While it is true athletes reported that they believed themselves to be asymptomatic after acute evaluations, there may be lingering effects such as slower response times and poorer performances on neuropsychological tests, when compared to their own baseline (Broglio, Macciocchi, & Ferrara, 2007a;

Kevin Guskiewicz et al., 2003; Warden et al., 2001). The addition of a test involving dynamic movements could be beneficial to ensure a safer return-to-play.

Previous studies by Catena and Parker have recommended the addition of tests involving dynamic movement (Catena, Donkelaar, & Chou, 2007; Parker, Osternig, & Donkelaar, 2007). Their studies focused on how a concussion affected the balance, gait, and obstacle avoidance in gait trials of college student-athletes. They were also tested while performing a cognitive task (answering simple questions) or an information-processing task (listening for an auditory signal). When the information-processing test was added, results indicated that the concussed participants become more aware of their gait and stability and that they adopt a more conservative gait. Noticing the differences from healthy and concussed student-athletes, the studies discussed the possibility of adding a variety of response time tasks and dynamic movements tests to check for effects that concussion could have.

A response time test could be done in conjunction with dynamic movements to check for lingering effects of a concussion. Response time, that is, the combination of reaction and movement time, is a very important variable in the athletic world as athletes are required to respond to multiple outside stimuli quickly (Schmidt, 1991). Reaction time measures how fast the brain and the central nervous system are able to identify the stimuli, process that information, and initiate the appropriate response. Movement time measures how long it takes to make that movement (Schmidt, 1991). Previous psychological studies have shown that response time is affected by both the Hick-Hyman law and the memory drum theory and both have a significant influence on interpreting response time (Henry & Rogers, 1960; Hick, 1952; Hyman, 1953).

The Hick-Hyman law considers the time it takes for an individual to make a decision based on the number of choices available and states simply, choice response time is linearly related to the amount of information that must be processed to solve the uncertainty of the alternative choices (Hick, 1952). Individuals are able to respond quickest in a simple reaction time test, since there is only one stimulus to process before reacting. Adding more choices leads to a slower response time because there are more choices to consider and more information to be processed. In Hick's study, participants were given a task that started out with just one choice, and then were gradually presented with more choices. Response time was noticeably slowed as more choices were added, up to a certain point (around 10 choices); then, increasing the number of choices had little effect on response time. However, the choices must be randomized and the participant must be unaware of how the stimulus will be presented, as prior knowledge invalidates the law. The study of Henry and Rogers in 1960 also found that response time was effected by the movement's complexity, also known as the memory drum theory. The more complicated a movement, the more time it takes to initiate that movement since more time is required to coordinate and direct the motor neurons and muscles (Henry & Rogers, 1960). If the athlete is responding to the same stimuli, and the movement is more complex, the response time will be slower. The testing of response time may be important to clinicians and researchers to explore how well an athlete is able to process information and perform correct sports related movements post-concussion. There have been a variety of methods of testing response time, depending specifically on what the investigators are looking to learn. Choice response time can be tested using a delayed setting, meaning that a delay of a certain amount of time will occur between stimuli (Schmidt, 1991). Other studies have used a continuous choice response time test without a delayed setting, for more sport-like tests involving foot movement and speed (Dunn-Lewis, Luk, & Comstock, 2012; Galpin, Li, Lohnes, & Schilling, 2008; Hydren, Kraemer, & Volek, 2013). Previous research has shown that response time is important in the sporting field to perform sport specific movement involving agility and foot speed (Hertel, Denegar, Johnson, Hale, & Buckley, 1999; Sheppard & Young, 2007).

Numerous studies have shown that a concussion affects response times, regardless of whether it is a simple response time test or a choice response time test (Broglio, et al., 2007b; Eckner, Kutcher, & Broglio, 2013; Eckner, Kutcher, & Richardson, 2010; Gardner, Shores, & Batchelor, 2010; Goodman, Meichenbaum, Gaetz, & Roy, 2001; Warden, et al., 2001). Both tests are valid measurements of a concussion's effects, though choice response time has a higher sensitivity rate (Goodman, et al., 2001). A computerized simple response time test done on USA boxing cadets showed that their response times four days post-concussion were slower than their baseline times, even though they reported being asymptomatic (Warden, et al., 2001). Broglio et al. in 2007 showed similar results in tests of recently concussed college athletes; who had slower computerized times in simple and choice response time tests, again even though the athletes said they were asymptomatic (Broglio, et al., 2007a). Rugby players who reported suffering multiple concussions had a significantly slower processing speed than those who had not suffered a concussion (Gardner, et al., 2010). Recently, when a drop ruler test, which is a simple response time test, was used on college athletes within 48 hours of a concussion incident; the athletes were shown to have a significantly slower response time than that indicated in their baseline (Eckner, et al., 2013; Eckner, et al., 2010). Response time can continue to be slower, even from those reporting themselves to be asymptomatic (Broglio, et al., 2007a; Covassin, Stearne, & Elbin, 2008; Warden, et al., 2001). These studies provide overwhelming evidence that response time slows down after the occurrence of a concussion.

As mentioned previously, these response time tests were done in static positions and did not take into account the extra time needed to perform more complex sport movements, according to the memory drum theory. To the author's knowledge, only one previous study has done a test involving dynamic movement and a choice response time on concussed college level student-athletes (Johnson, Hertel, Olmsted, Denegar, & Putukian, 2002). They used the Cybex Reactor, a computerized agility trainer, where a student-athlete was asked to respond to light stimuli by moving to the correct circle. The purpose of the investigation was to see if there was a significant difference in response time between healthy student-athletes and recently concussed student-athletes over a 10-day period. Their results showed that the response times of concussed student-athletes were not significantly different from those of healthy student-athletes during the 10-day testing period. While this study did incorporate a dynamic movement, a major limiting factor was that the same pattern was used in every testing session. This created a possible learning effect, potentially limiting the information-processing factor of response time, as the student-athletes could potentially anticipate what to do next. Johnson et al.(2002) suggested that future experiments should use random sequences to minimize this learning effect to determine the true impact of the concussion (Johnson, et al., 2002; Sheppard & Young, 2007).

The addition of a response time task with dynamic movement is important, since there is a possibility that student-athletes could still be suffering lingering effects when returning to the playing field. Extra precaution is needed since student-athletes who had a previous concussion, are three to six times more likely to get another concussion (Kevin Guskiewicz, et al., 2003; Kevin Guskiewicz, Weaver, Padua, & Garrett, 2000; Zemper, 2003). Those who have suffered cumulative effects have been shown to have a slower recovery with more severe symptoms, which could lead to long-term mental disorders (Collins, Lovell, Iverson, Cantu, & Maroon, 2002; KM Guskiewicz, McCrea, Marshall, & al, 2003; Iverson, Gaetz, Lovell, & Collins, 2004; Slobounov, Cao, & Sedatianelli, 2009; Covassin, 2010). Research is still being done on the relationship between concussions and muscular skeletal injuries. However, it seems that those who have had concussions or multiple concussions have a greater chance of suffering a non-contact muscular-skeletal injury (Herman, 2013; Swanik, Covassin, Stearne, & Schatz, 2007; Taimela et al., 1990).

While studies have examined the effects that concussion can have on the brain and on cognition, there have been only limited choice response time tests involving dynamic movement with an athletic component. It would be beneficial to examine the effect of a concussion on dynamic movement, since this could help trainers and health care officials make better return-to-play decisions. Therefore, the primary purpose of this investigation is to examine the effect of a concussion on dynamic random response time tests, one with a delay (similar to a computerized test) and one without (similar to previous computerized agility trainers) on the day a student-athlete returns to full athletic participation. It is hypothesized that the recently recovered student-athletes would perform significantly slower in a delayed choice response time task and a continuous choice response time task than the healthy student-athlete.

CHAPTER 2

METHODS

Participants

Sixteen student-athletes from a NCAA Division I athletic program participated in this study. Information on the demographic history can be seen in Appendix C in table 1. The athletic training staff at the institution helped in the identification and recruitment of concussed and healthy student-athletes. Interested student-athletes met with a member of the research team who explained the study, answered any questions, and received written informed consent as approved by the university's Institutional Review Board (Appendix D). Eight recently recovered student-athletes (RRSA) who had suffered a concussion, and 8 healthy student-athletes (HSA) were recruited.

Six of the RRSA suffered a Grade 2 concussion while 2 suffered Grade 3 concussions based on the Cantu grading scale (Cantu, 2001). The details of the Cantu grading scale are available in Appendix C in table 2; RRSA followed the recovering protocol under the supervision of the athletic training staff and health care providers of the university. Details of the protocol can be found in Appendix E. Briefly explained, when a concussion occurred, the student-athletes were restricted from all athletic participation and physical activity. They were also told to rest cognitively, by minimizing the amount of school work, computer usage, reading, television viewing or any other activity that would require concentrating or paying attention for a period of one day. After one day of rest, they were allowed to have a low level amount of cognitive activity. During this period, the student-athletes were periodically tested and the results were compared to their own baseline results. These tests were the Balance Error Scoring

System (BESS), Standardized Assessment of Concussion (SAC), and the Immediate Post-concussion Assessment and Cognitive Testing (ImPACT). Until the individual was asymptomatic and test scores had returned to normal, the student-athlete performed no exercise or any physical activity. Once the individual was asymptomatic and had achieved baseline scores in all tests, a 7-day graded exercise protocol was started. The first routines consisted of light aerobic exercise done on a stationary bicycle, followed by sport specific drills, then non-contact sport practice, eventually moving to full practice. If any concussion symptoms were reported, the individual was returned to the previous day's exercises. This protocol followed the recommendations from the International Conference on Concussion on how to safely return athletes to the playing field (McCrory, Meeuwisse, Aubry, Cantu, & Dvorak, 2013). The RRSA group consisted only of student-athletes who successfully went through the protocol and were returning to their first day of full, active athletic participation as determined by a certified athletic trainer under the supervision of the team physician. RRSA returned to full active participation in 19.3 ± 13.1 days.

The control group was made up of healthy student-athletes (HSA); full time student-athletes who were already in full participation for their sport. HSA were matched to a participant in the RRSA group by gender, sport, and if possible, by position. This matching was similar to what was done in Johnson's dynamic response time study (Johnson, Hertel, Olmsted, Denegar, & Putukian, 2002).

Potential participants for both groups were excluded if they were suffering from any lower extremity muscular skeletal injury that affected movement or balance within the past 3 months. This included injury to the back, knees, ankles, legs or foot. Participants were also excluded if they had a previous history of psychiatric illnesses, neurologic history, or traumatic brain injury besides those caused by a concussion. Two of the HSA had previously suffered a concussion; one, 13 months prior to the study; and the other, 10 months earlier. Inclusion criteria for both groups were that they had to be student-athletes who were active members of one of the university's athletic teams; those that regularly participated in practices and in competitions.

Eleven RRSA were recruited for the study; however 2 suffered an ankle sprain less than one month prior to the testing day. Another participant in the RRSA group did not show up at the agreed-upon time for testing and was not able to come at a later time. Nine HSA were recruited, however one HSA had difficulty completing the task and was thus disqualified. As a result, 8 RRSA and 8 HSA participated in this study.

Instrumentation

Response time was measured using a Quickboard (LLC Memphis, Tennessee). Quickboard is a computerized agility trainer that is commercially available and commonly used for training athletes in different aspects of athletic participation, such as response time. A previous study ensured that the reliability rate was 0.89, while precision was 2.6 % (Galpin, Li, Lohnes, & Schilling, 2008). The Quickboard (l17cm x 91.5cm x 1.9cm) is a non-slip mat positioned on the ground with 5 circular sensor pads (diameter 22.4 cm) placed in five different locations (one in each corner and one in the middle). An image of the Quickboard matt is provided in Appendix F. The Quickboard connects to an Archos 101 Internet tablet (Igny, France) that is placed on a tripod directly in front of the participant (0.7 m). An image of the table is provided in Appendix F. The tablet shows a picture of the Quickboard mat and highlights the correct circle to step on and also records all the response time data from the participants.

Procedure

On testing day, participants reported to the Biomechanics Lab and filled out the Health and Activity questionnaire (Appendix D) to ensure that the participants were eligible to participate. Height, weight, and age were also recorded during this time. The RRSA were considered fully recovered from their concussions and were cleared for full-unrestrictive athletic participation by certified athletic trainers under the supervision of the team's physician. All the HSA had been cleared for full-unrestricted athletic participation by a certified athletic trainer under the supervision of the team's physician. All testing was done prior to any athletic practices of any sort. The same methodologies were used for both groups.

A delayed choice response time task and a continuous choice response time task were used for testing. When initiating the tasks, the participants stood astride the center pressure pad in a neutral position. A random start was used to initiate the beginning of both tasks. The tablet randomly lit up one of the 5 circles; the participants would then step on the corresponding circle. When the participants stepped on the correct circle, a new circle would light up. The Quickboard computer program, ensuring that the trials remained random, chose the next circle that was lit up. If the participants stepped on the incorrect circle, a loud beep would alert the participants to the mistake. A new circle would not light up until the participant had stepped onto the correct one. The delayed choice response time task was performed first, followed by the continuous choice response time task.

For the delayed choice response time task, the participants would always start in a neutral position and touch a different randomly designated pressure pad 10 times. When one of the circles lit up, the student-athletes would tap it as fast as possible and then return to the neutral position. A new circle would light after a random delay of 3 – 5 s. The test would continue until 10 correct touches had been achieved. The tablet recorded all errors committed by the participants, but errors were not tallied as part of the correct 10-touch count. The delay setting was chosen for two reasons; because many traditional choice response time studies incorporate a delay and so as to have a procedure similar to that of Johnson's dynamic response time study (Johnson, et al., 2002; Schmidt, 1991).

For the continuous choice response time task, the participants were required to correctly touch randomly selected pressure pads as quickly as possible 30 times. There was no delay in revealing the next pad to touch and the participant did not have to return to a neutral position. Any errors committed by the participant were recorded by the tablet and contained the information as to where and when the error was committed. Errors were not tallied as part of the 30 touches. Previous studies that have used Quickboard had used a variation of a continuous response time tasks (Dunn-Lewis, Luk, & Comstock, 2012; Galpin, et al., 2008; Hydren, Kraemer, & Volek, 2013).

To become familiar with the particular task, participants had 3 practice trials for each test. After completion of the practice trials, the participant performed 5 trials of each test. In the delayed choice response time task, the participants had a one-minute rest between trials. As the continuous choice response time task involved more physical activity, there was a two-minute rest between each trial.

Data Analysis

The independent variable analyzed were the participants' concussion status; RRSA versus HSA. The dependent variable that was analyzed for the delayed choice response time task was the trial that had the fastest mean time. In the continuous choice response time task, only the fastest completion time was used for analysis. Data from the fastest trial was utilized because previous studies using Quickboard selected those trials (Galpin, et al., 2008). Due to the low numbers of participants, a Mann-Whitney U rank test was used to find significant differences between the RRSA and the HSA groups. Seven tests were run; 4 tests to determine differences in demographics (age, height, weight, and concussion history), while the other 3 were to investigate differences in the delayed choice response time task, the continuous choice response time task and any errors that were made.

Chapter 3

RESULTS

In the delayed choice response time task, there were no significant differences between the RRSA and the HSA groups (U=31, *p=0.*91*)*. RRSA had a mean time of 0.68 ± 0.06 s and the HSA had a mean time of 0.70 ± 0.06 s (Appendix C, Table 3). In the continuous choice response time task, there was no significant difference between the RRSA and the HSA groups (U=25, *p*=0.40). The RRSA had a mean time of 21.6 ± 2.46 s (Appendix C, Table 4), while the HSA had a mean time of 20.8 ± 2.92 s. No errors were made in the delayed choice response time task. Errors were made in the continuous task; however no significant differences were found (U=27, *p=0.76)*. RRSA had a mean error rate of 0.75 ± 1.43 errors and the HSA had a mean error rate of 0.87 ± 0.99 errors. Graphs comparing group averages and individual response times can be seen in Appendix C Figure 1-4. No statistical differences could be found in age (U=26, p=0.51), height (U=25, *p*=0.46) or weight (U=30, *p*=0.83).

A post-hoc power analysis was done on delayed choice response time, continuous choice response time, and the error rate. Low power is normally considered below 0.2 and in this study a very low power rate was found in all three categories. The delayed choice response time had a power of 0.11, the continuous choice response time of 0.08, and the error rate of 0.04. This indicates that the population size was too small and that adding more participants in each group would have been very beneficial. The study was limited to one year, which limited the number of participants in the study.

Also of note is that HSA #7 had a much slower response time than all of the participants in the study, regardless of which group they were in. This participant was 3.1 seconds slower than then slowest RRSA in the continuous choice response time task. This is possibly due to the effects of motivation, or the lack of it. Four HSA members had a much faster time than their matched RRSA by at least 2.5 s in the continuous choice response time task. These differences can be seen in Figure 2 of Appendix C.

Chapter 4

Discussion

The purpose of this study was to investigate differences in the delayed choice response time and continuous choice response time between student-athletes who recently recovered from their concussions and healthy student-athletes. The results of the study indicate that there were no significance differences in delayed response time, continuous choice response time, or in the error rate. To the author's knowledge, this is only the second time a response time involving dynamic movement was investigated.

Previous response time studies done without dynamic movement were able to show that concussed participants had slower response times; however in this study no statistical differences between RRSA and HSA were found. A major reason may be that many response time studies tested their participants within a week of their concussions (Broglio, Macciocchi, & Ferrara, 2007; Eckner, Kutcher, & Broglio, 2013; Goodman, Meichenbaum, Gaetz, & Roy, 2001; Warden et al., 2001). Those response time studies were done in static settings involving the use of a computer or drop-ruler test, when the participants were still in the acute injury phase of recovery; the days immediately after they were concussed, and still suffering symptoms from the concussion. Other studies have shown that given adequate rest time, participants' response times return to baseline within a few weeks of the concussion. One study showed that on average, most of his participants reported to be asymptomatic in 8.14 ± 6.48 days and that response time (using ImPACT) returned to baseline values (Broglio, et al., 2007). Collie et al. showed similar results in 2006 (Collie, Makdissi, Maruff, Bennell, & McCrory, 2006). His subjects took 11 days to be asymptomatic and see their response time on ImPACT return to baseline values. Again similar results were seen in Collins et al. (2003) study; those who reported to be asymptomatic after 7 days, had a reaction time returned to normal (Collins et al., 2003). On a lengthier scale, Covassin et al. (2010) showed that nearly all participants response times returned to baseline after 21 days; although some individuals did have a quicker recovery and returned to baseline within 14 days (Covassin, Elbin, & Nakayama, 2010). In this study, the university's health care providers deemed all of the RRSA fully recovered from their concussion after 19.3 ± 13.1 days, a timeframe similar to the Covassin study. Additionally, the RRSA were no longer suffering from any of the post-concussive symptoms of the concussion and it is possible given this timeframe, their response times could have recovered as well.

Within this study, there was no single, consistent day for testing all participants, as was done in previous response time studies; rather testing was done after completing the final stage of the return-to-play protocol (Covassin, Stearne, & Elbin, 2008; Eckner, et al., 2013; Eckner, Kutcher, & Richardson, 2010; Warden, et al., 2001). In this study, RRSA could not be tested until institutional athletic and health care officials determined the participant had recovered from his or her concussion. This decision was based on when their symptoms dissipated, when the mandatory tests (balance, cognitive, and computerized neurocognitive) returned to baseline, and when they were found to be asymptomatic during the progressive exercise protocol. While this helps healthcare providers make better decisions about when to return the participants to play, it does make it very difficult to predict an exact test date. Participants returned to full active play within 19.3 ± 13.1 days, similar to the results of the Covassin study (Covassin, et al., 2010). It is possible that the number of days between the occurrence of the concussion and the testing date gave the RRSA enough time to have their response times return to normal.

Additionally, having the testing date determined by following the University's return-to-play protocol, presented a unique problem. The National Collegiate of Athletic Association (NCAA) lacks a universal policy on concussion, for the most part, letting universities set their own concussion guidelines, with a few exceptions. For example, if an athlete receives a concussion or is believed to possibly have suffered a concussion, the athlete is not allowed to return to the playing field that day (NCAA, 2012-2013). These guidelines are then supplemented by the recommendations of the 3rd and the 4th International Conference of Concussion (McCrory, Meeuwisse, ..., & Cantu, 2009; McCrory, et al., 2013). However, as a result, each institution may have a different return-to-play protocol. This means that the test battery itself and the number of rest days may differ at each institution. Therefore, it is possible that using a population from another institution will lead to different results, since the return to play protocol may be different, thereby affecting scheduling the test date.

To the author's knowledge, Johnson et al's. (2002) study is the only one that involves concussion and dynamic movement choice response time. As was explained previously, the major limitation to Johnson et al's. (2002) was that the response time task was not random, so participants could potentially memorize the pattern and anticipate the next movement affecting the results, a limitation noted by the investigators in that study. In this study randomizing all choice response tasks circumvented this limitation. However, as was the case for Johnson et al's. (2002) study, there were still no statistical differences found between the two groups. Here, the lack of significant differences may be the result of this study being underpowered as Johnson et al (2002) had 84 participants versus the 16 in this study. Another possible complication could stem from the lengthy recovery time that the RRSA were given, so that RRSA may have fully recovered by the time they were tested. .

Since not many concussion studies have incorporated dynamic movements in their response time (specifically using the Quickboard), it remains unknown if the results that were obtained are common in the athletic population. Other response time studies have incorporated dynamic movements using a similar methodology; therefore it would be beneficial to see how the results of this study compare to others (Dunn-Lewis, et al., 2012; Gonzalez et al., 2013; Hydren, et al., 2013). Despite differences in population and environment, some performance similarities were found.

Galpin et al's. (2008) study was examining the effects that training on a computerized agility trainer could have on choice response time and foot speed. The publication provided baseline and post-training results. When comparing baseline data on how long it took to do 10 touches, Galpin et al's. (2008) experimental group had a baseline time of 5.74 ± 1.17 s and the control group had a time of 4.94 ± 0.97 s. In this study, RRSA had a time of 7.47 ± 0.99 s, while the HSA had a time of 7.18 ± 0.69 s, indicating that Galpin et al's (2008) group performed much better when looked at clinically. This is particularly interesting, since Galpin et al's. (2008) population was made up of a trained group; still, none of his subjects had the training of the typical participant in this study. Galpin et al's (2008) allowed both of his groups to have a one-day practice session before data was collected. This study did not do that. So it is possible that a faster time may be a product of simply having more time to practice.

Gender differences accounted for another variable. In the general population, males have been shown to have a faster reaction time (Der & Deary, 2006; Fozard, Vercruyssen, Reynolds, Hancock, & Quilter, 1994). Most participants in this study were females and anecdotal comparisons seem to back up the studies on the general populations; females had a slower response time than males. Although Galpin's population consisted of mostly males, he stated that there were no significant differences between males and females. In this study, some of the female participants performed just as quickly as the men.

Other dynamic choice response time studies using the same equipment had similar results to this study (Dunn-Lewis, et al., 2012; Hydren, et al., 2013). Dunn-Lewis et al. (2012) explored the effects of mouth guards on a variety of factors, one of them being response time. Dunn-Lewis et a.l (2012) did have a collegiate student-athlete population; however, they came from speed and agility oriented sports. Dunn-Lewis et al's. (2012) fastest mean response time was in the range of 0.33 ± 0.42 s, while the RRSA had an average fastest time of 0.401 ± 0.13 s, and the HSA had an average of 0.31 ± 0.14 s. This shows that the ranges of the fastest times were similar in the two studies. Hydren et al. (2013) explored the effects of altitude on skiers on a variety of performance factors, one of them being a dynamic choice response. When comparing baseline scores, it took Hydren et al's participants 0.75 s to go from one dot to another in a continuous choice response time task. Similarly, in this study, the RRSA were able to perform it in 0.73 s, while the HSA were a bit faster at 0.71 s.

It was assumed that all participants would perform to the best of their ability. However one of the participants, a healthy student-athlete who is a male football player, was 5 to 7 s slower in the continuous choice response time task, more than 2 standard deviations from the mean. This was a clinically slower time than that of the other participants. It is possible that he was not motivated to perform to the best of his ability. However, this is difficult to determine with any certainty, since this study did not have any tests or questionnaires to assess motivation. One indication of a possible lack of motivation, as noted by the principal investigator, was that the football player seemed "uninterested in the task, was quiet, and was not interested in the results of previous participants". This contrasted with the enthusiasm exhibited by the other participants, who seemed to appreciate the challenge, asked about other participants' times, and upon learning the other participants' results, expressed their desire to attempt to achieve a faster time. This raises another interesting point, whether the participants who were tested later had a motivational advantage over those who came earlier, since they had a general knowledge of what had occurred previously.

Given the apparent lack of motivation of HSA #7, there was some curiosity about the effect of motivation on the other participants. One might question whether the participants that were tested later had a faster response time, because they had greater knowledge of previous response times and could compete. It was a concern since nearly all members of the RRSA group were tested before the HSA group. However, as the results showed, if this provided any advantages to the HSA group, it was statistically insignificant as there were no significant differences between the two groups in any of the tasks. Within the groups, there seems to be little differences as well, excluding male participants, In the RRSA group, the first half of the participants tested had a mean time of 22.96 $\pm$ 2.11 s and the latter half tested had a time of 22.57 $\pm$ 0.93 s. In the HSA group, the first half tested had a time of 20.91 ± 0.74 s and the latter half tested had a mean time of 19.30 ± 1.21 s. Those tested in the latter half in both groups had a slightly faster time, though perhaps this is not a meaningful difference. While no study has been done on the effects of motivation on Quickboard performance, it can be subjectively observed how motivation affects response time using Quickboard. More research on how motivation could affect response time in the Quickboard and the possibility of adding an incentive could be beneficial to achieve faster response times. However, this is not feasible in a study involving collegiate student-athletes due to NCAA regulations on receipt of benefits.

A major limitation of the study was the small sample size. A post-hoc power analysis revealed that the power was only 0.08. With such a low power in the study, it is difficult to judge how significant the results really are. Perhaps if it had been possible to have more participants, statistical differences might have been found within the two groups. A prospective power analysis showed that at least 15 participants for each group for a total of 30 participants would have been needed to have an adequate power level of 0.8. However, time constraints and the fact that there were fewer cases of concussed student-athletes than anticipated, limited the study.

Another limitation to the study was the lack of a baseline, as done in many other sport response time and concussions response time studies (Broglio, et al., 2007; Eckner, et al., 2013; Galpin, et al., 2008; Hydren, et al., 2013; Warden, et al., 2001). No baseline data collection could be done, as it is impossible to anticipate when or if a participant might receive a concussion. This would have required baselining all the institution's student-athletes; a task beyond the scope of the study, as neither the necessary financial nor human resources were available.

There was discussion about how this situation could be remedied. One idea was to incorporate the methodology and equipment used for these tests into the warm-up sessions of all student-athletes, which would make recent and accurate baseline data consistently available.

Future studies should increase the number of participants, since a larger sample size is necessary to receive a significant statistical power. As stated before, at least 15 participants in each group would have been needed to achieve a satisfactory 0.8 power level. It is suggested that if a future study is conducted, it be done at this institution to ensure that the methodology and university protocols are the same. However, it would be possible to conduct the study at a different institution as long as all the student-athletes are at the same institution and covered by the same concussion regulations.

Adding a test or questionnaire to check for motivational levels could be beneficial to determine if the participant is performing to the best of their ability. The impact of practice should be taken into account, as some participants might not have any experience with the test (Galpin, et al., 2008; Johnson, et al., 2002). For many of the participants in this study, it was the first time they have ever performed a response time test using this particular instrument. During the practice trials, many participants had some difficulty performing both tasks and were usually performing 2 standard deviations slower than the mean regardless of the group they were in. However during the data collection trials, many participants were within half a standard deviation from their own fastest time. There were some exceptions, as small number of participants seemed to require more practice to achieve response times closer to the mean. It would be beneficial to see how many practice sessions would be necessary to minimize a learning effect and receive a true response time result.

Conclusion

No significant differences could be found between the RRSA and the HSA, and both groups had response time scores similar to previous studies using the same equipment and similar test protocols. It is possible that participants' response time had fully recovered by the end of the return-to-play protocol. While no statistical differences were found, the statistical power was low. It is possible if the investigation had continued and there were more participants, a statistical difference might have been found.

REFERENCES

1. Broglio, S., Macciocchi, S., & Ferrara, M. (2007a). Neurocognitive performance of concussed athletes when symptom free. *Journal of Athletic Training, 42*(4), 504-508.
2. Broglio, S., Macciocchi, S., & Ferrara, M. (2007b). Sensitivity of the concussion assessment battery. *Neurosurgery, 60*(6), 1050-1058.
3. Catena, R., Donkelaar, P. v., & Chou, L.-S. (2007). Altered balance control following concussion is better detected with an attention test during gait. *Gait & Posture*, 406-411.
4. Collins, M., Lovell, M., Iverson, G., Cantu, R., & Maroon, J. (2002). Cumulative effects of concussion in high school athletes *Neurosurgery, 51*(5), 1175-1181.
5. Covassin, T., Stearne, D., & Elbin, R. (2008). Concussion history and post-concussion neurocognitive performance and symptoms in collegiate atheltes. . *Journal of Athletic Training, 43*(2), 119-124.
6. Dunn-Lewis, C., Luk, H.-Y., & Comstock, B. (2012). The effects of a customized over-the-counter mouth guard on neuromuscular force and power production in trained men and women. *Journal of Strength and Conditioning Research, 26*(4), 1085-1093.
7. Eckner, J., & Kutcher, J. (2010). Concussion symptom scales and sideline assessment tools: A critical literature update. *Current Sport Medicine Reports, 9*(1), 8-15.
8. Eckner, J., Kutcher, J., & Broglio, S. (2013). Effect of sport-related concussion on clinically measured simple reaction time. *British Journal of Sports Medicine, Published online first*(10.1136/bjsports-2012-091579).
9. Eckner, J., Kutcher, J., & Richardson, J. (2010). Pilot evalution of a novel clinical test of reaction time in national collegiate athletic association division I football players. *Journal of Athletic Training, 45*(4), 327-332.
10. Galpin, A., Li, Y., Lohnes, C. A., & Schilling, B. K. (2008). A 4-week choice foot speed and choice reaction training program improve agility in previously non-agility trained, but active men and women. *Journal of Strength and Conditioning Research, 22*(6), 1901-1907.
11. Gardner, A., Shores, A., & Batchelor, J. (2010). Reduced processing speed in rugby union players with three or more previous injury. *Archives of Clinical Neuropsychology, 25*(3), 174-181.
12. Giza, C., & Hoyda, D. (2001). The Neurometabolic cascade of concussions. *Journal of Athletic Training, 36*(3), 228-235.
13. Goodman, G., Meichenbaum, D., Gaetz, M., & Roy, E. (2001). A chronometric approach to assessment of mild head injury in sports (abstract). *International Symposium on Concussion in Sport, 35*, 367-377.
14. Guskiewicz, K., McCrea, M., Marshall, S., & al, e. (2003). Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussio Study. *JAMA, 290*(19), 2549-2555.
15. Guskiewicz, K., McCrea, M., Marshall, S., Cantu, R., Randolph, C., Barr, W., . . . Kelly, J. (2003). Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA concussion study. *Journal of the American Medical Association 290*(19), 2549-2555.

16. Guskiewicz, K., Weaver, N., Padua, D., & Garrett, W. (2000). Epidemiology of concussion in collegiate and high school football players. *American Journal of Sports Medicine, 28*(5), 643-650.
17. Henry, F., & Rogers, D. (1960). increased response latency for complicated movements and a "Memory Drum" theory of neuromotor reaction. *Research Quarterly, 31*(621-652).
18. Herman, D. (2013). *Athletes with concussions risk lower extremity injuries at return-to-sport.* . Paper presented at the American Medical Society for Sports Medicine, San Diego.
19. Hertel, J., Denegar, C., Johnson, P., Hale, S., & Buckley, W. (1999). Reliability of the Cybex Reactor in the assessment of an agility task. *Journal of Sport Rehabilitation, 8*, 24-31.
20. Hick, W. (1952). On the rate of gain of information. *Quarterly Journal of Experimental Psychology, 4*(1), 11-26.
21. Hydren, J., Kraemer, W., & Volek, J. (2013). Performance changes during a weeklong high-altitude alpine ski-racing training camp in lowlander young athletes. *Journal of Strength and Conditioning Research, 27*(4), 924-937.
22. Hyman, R. (1953). Stimulus Information as a determinant of reaction time. *Journal of Experimental Psychology, 45*, 188-196.
23. Iverson, G., Gaetz, M., Lovell, M., & Collins, M. (2004). Cumulative effects of concussion in amateur athletes. *Brain Injury, 18*, 433-443.
24. Johnson, P., Hertel, J., Olmsted, L., Denegar, C., & Putukian, M. (2002). Effects of mild brain injury on an instrumental agility task. *Clinical Journal of Sport Medicine, 12*(1), 12-17.
25. Johnston, K., Bloom, G., Jim, R., Kissick, J., Montgomery, D., Foley, D., . . . Ptito, A. (2004). Current concepts in concussion rehabilitation. *Current Sport Medicine Reports, 3*, 316-323.
26. Langlois, J., Rutland-Brown, W., & Wald, M. (2006). The epidemiology and impact of traumatic brain injury. *Journal of Head Trauma Rehabilitation, 21*(5), 375-378.
27. McCrea, M., & Guskiewicz, K. (2003). Acute effects and recovery time following concussion in collegiate football players. *Journal of the American Medical Association, 290*(19), 2556-2563.
28. McCrea, M., Guskiewicz, K., Randolph, C., Barr, W., Hammeke, T., & Kelly, J. (2009). Effects of a symptom free waiting period on clinical outcome and risk of reinjury after sport-related concussion. *Neurosurgery, 65*(5), 876-883.
29. McCrory, P., Meeuwisse, W., ..., & Cantu, R. (2009). Concensus Statement on Concussion in sport: The 3rd International Conference on Concussion in sport, held in Zurich, November 2008. *Journal of Clinical Neuroscience, 16*, 755-763.
30. McCrory, P., Meeuwisse, W., Aubry, M., Cantu, B., & Dvorak, J. (2013). Concensus statement on concussion in sport: The 4th international conference on concussion in sport held in Zurich, November 2012. *British Journal of Sports Medicine, 47*, 250-258.
31. Parker, T., Osternig, L., & Donkelaar, P. v. (2007). Recovery of cognitive and dynamic motor function following concussion. *British Journal of Sports Medicine, 41*, 868-873.
32. Schmidt, R. (1991). *Motor learning and performance*. Champaign, IL: Human Kinetics.
33. Sheppard, J., & Young, W. (2007). Agility literature review: Classifications, training, and testing. *Journal of Sports Science, 24*(9), 919-932.

34. Slobounov, S., Cao, S., & Sedatianelli, W. (2009). Differential effects of first versus second concussive episodes on wavelet information quality of EEG. *Clinical Neurophysiology*, *120*, 862-867.
35. Swanik, C., Covassin, T., Stearne, D., & Schatz, P. (2007). The relationship between neurocognitive function and noncontact anterior cruciate ligament injuries. *American Journal of Sports Medicine*, *35*(6), 944-949.
36. Taimela, S., Osterman, K., Kujala, U., Lehto, M., Korhonen, T., & Alaranta, H. (1990). Motor ability and personality with reference to soccer injuries. *Journal of Sports Medicine and Physical Fitness*, *30*, 194-201.
37. Tracey Covassin, R. J. E., Yusuke Nakayama. (2010). Tracking Neurocognitive Performance Following
38. Concussion in High School Athletes. *The Physician and Sports Medicine*, *38*(4).
39. Warden, D., Bleiberg, J., Cameron, K., Ecklund, S., Walter, J., Sparling, M., . . . Arciero, R. (2001). Persistent prolongation of simple reaction time in sports concussion. *Neurology*, *57*(3), 524-526.
40. Zemper. (2003). Two-year propective study of a relative risk of a second cerebral concussion. *American Journal of Physical Medicine Rehabilitation*, *82*(9), 653-659.

APPENDIX A

HYPOTHESIS, LIMITATION, DELIMITATION, ASSUMPTION

Hypothesis

- Student-athletes who recently recovered from a concussion would have a significantly slower delayed choice response time when compared to healthy student-athletes.
- Student-athletes who recently recovered from a concussion would have a significantly slower continuous choice response time when compared to healthy student-athletes.

Limitation

Since it was uncertain who would receive a concussion during the time of the study, the exact sample size was not known until the completion of study. A learning effect was possible with using new equipment, though the practice trials were an effort to minimize this.

Delimitation

Only student-athletes from Georgia Southern University were used for the study. All participants had no lower body extremity injuries that could affect moving or balance within the past 3 months. Participants must also have had no previous history of psychiatric illnesses, neurologic history, or traumatic brain injury besides those caused by the concussion.

Assumption

It was expected that all instruments used were reliable and accurate. It was assumed that all participants would perform to the best of their abilities. It was also assumed that the Institution’s medical staff would be able to correctly diagnose when a concussion had occurred and that the concussion protocols would be properly followed.

APPENDIX B

LITERATURE REVIEW

In recent years, there has been a growing amount of research focusing on concussions, which has been accompanied by an increasing public awareness of this phenomenon. In particular, research has focused on the diagnosis of the concussion as well as the impact a concussion has on an individual's cognitive ability and physical ability. A considerable amount of research has been done on the prevention of concussions as well as how to safely return an athlete to full participation in his or her given sport. Through there has been a significant growth in the knowledge and database about concussions, there are still concerns about the pathophysiology of concussions, recovery, and proper return to play protocols for athletes. Likewise it is necessary to expand the studies to determine how impairment in reaction times and neurocognitive abilities caused by concussions, impacts an athlete's health and abilities on the field.

In 2008 and recently in 2012, The 3rd and 4th International Conference on Concussion in Sport defined concussions as a complex pathophysiological process affecting the brain, that is induced by traumatic biomechanical forces (McCrory, Meeuwisse, ..., & Cantu, 2009; Paul McCrory, Meeuwisse, Aubry, Cantu, & Dvorak, 2013). In order for a concussion to occur, the biomechanical force can be a direct blow to the head, neck or face. An indirect hit to the body that causes an "impulsive force" to be transmitted to the head (such as a powerful whiplash or the body slamming the ground, followed by the head) can also cause a concussion (McCrory, et al., 2009; Paul McCrory, et al., 2013).

What is not clear and is being discussed is how strong that biomechanical force or compulsive force needs to be in order to cause a concussion. Likewise, another question is whether biomechanical forces from multiple, minor non-concussive, cumulative hits to head will eventually lead to a concussion. There have been a series of biomechanical studies that tried to determine what impact threshold was necessary for a concussion (Brolinson et al., 2006; Guskiewicz et al., 2007; Mihalik, Bell, Marshall, & Guskiewicks, 2007; Stefan Duma et al., 2005). However, no definitive findings have been reached, because there has been a lack of similar results from multiple researchers.

Studies done on collegiate football players have shown that the average force experienced by college football players were 20.1g and 22.1, respectively, and were directed to the top of the head or to the facemask (Brolinson, et al., 2006; Mihalik, et al., 2007). In another similar study, the results show that the average impact force was 32g and with one concussive force above 82g (Stefan Duma, et al., 2005). Studies that were done on professional football players of the National Football League (NFL), found the biomechanical force that was hitting the players' head was significantly higher, averaging about 98g (Pellman, Viano, Tucker, & Casson, 2003). These studies show a wide range of possible impact force that could possibly end in a concussion, with relatively minor impacts still ending in a concussion (Brolinson, et al., 2006; Mihalik, et al., 2007; Stefan Duma, et al., 2005). In a similar biomechanical study, Guskiewicz et al., (2007) discussed how there was little relationship between linear or rotational force impact magnitudes and the severity of the concussion or if the athlete will even suffer one. An athlete is able to receive a concussion from a wide range of possible forces and should therefore be evaluated individually (Guskiewicz, et al., 2007)

These studies show that there currently is no-conclusive information on the exact amount of force that is needed to concuss a football player, as there seems to be no possible threshold that is necessary. A study was to see whether there was any correlation between the severity of the concussion and the strength of the impact force that an athlete received (McCaffrey, Mihalik, Crowell, Shields, & Guskiewicz, 2007). McCaffrey et al.'s (2007) kept track of the amount of force that the head of each player received by putting small accelerometers inside the helmets of all the players, called Head Impact Telemetry System which kept track of forces in real time. McCaffrey et al. (2007) performed baseline testing for all the athletes and then tested concussed athletes within 48 hours of the impact of the concussion. McCaffrey et al, (2007) kept track of the severity of the players' symptoms, the duration of said symptoms, and the progress of their recovery. The results of the study showed that there was little correlation between impact force and severity of the concussion (McCaffrey, et al., 2007). The fact that an athlete is suffering a powerful blow, does not indicate that an athlete will suffer a concussion, nor does it indicate the severity of the concussion, according to his study (McCaffrey, et al., 2007).

For example, there was little difference between athletes who suffered a concussion from a minor hits (60g's) and those who took more intense hits (90gs) (McCaffrey, et al., 2007). It could be suggested that one athlete's concussion is "different" from another athlete's concussion. Athletic trainers and other medical personnel should take this into consideration when treating an athlete to determine what could possibly be the best treatment. Rather than treating all concussed athletes as a group, they should rather treat each concussed athlete differently and individually to determine what is the best diagnoses and recovery for the particular athlete. Regardless of the actual force, once an athlete's brain has been affected by a force strong enough to induce a concussion, a series of changes occur within that affects the neurons of the brain. The pathophysiology of a concussion is a complicated process that involves a series of Neurometabolic steps. The impact of the concussion can be felt rapidly, seconds after its occurrence (Giza & Hoyda, 2001). But side effects may occur hours after the occurrence of the concussion, as the accumulation of ions and by-products of mechanisms start to take their toll(Giza & Hoyda, 2001). This in turn leads to the different symptoms that many athletes suffer. Depending on the severity of the concussion, it may take several days and or even weeks for the brain and the affected neurons to recover from the concussion (Eckner & Kutcher, 2010; McCrory, et al., 2009).

While there has been no study directly examining the human brain after a concussion, there have been observations of the impacts of concussions on the brains of laboratory rats (Giza & Hoyda, 2001). Giza and Hoyda (2001) performed a thorough literature review in 2001 observing the Neurometabolic cascade of a concussion and the results of that cascade. They reported that the brain does not go through any physical change in regards to structure or neuron connectivity. Rather a series of chemical and physiological changes occur within an individual brain cell's synapse, as its metabolism causes ionic shifts(Giza & Hoyda, 2001). This disruption and a lack of blood supply causes damage to the brain's neurons and in some cases apoptosis (cell death)(Giza & Hoyda, 2001).

Immediately after a biomechanical force causes a concussion, there occurs nonspecific and abrupt depolarization of surrounding neurons, which causes neurotransmitters to be released, damaging the membrane and causing a significant disruption to ionic homeostasis. As a result of axonal stretching, impact damage done to the membrane and the opening of voltage-dependent Potassium (K+) pumps in the membrane, there is a leakage of K+ to the outside of the cell (Giza & Hoyda, 2001). As nonspecific and random depolarization of surrounding neurons continues, there is a constant release of neurotransmitters, specifically the excitatory amino acid glutamate. The release of glutamate activates kainite, NMDA, and AMPA across the synaptic cleft and within the neuron(Giza & Hoyda, 2001). This action further increases the amount of K+ to the outside of the cell, simply because of the normal physiology of neurons.

Normally, extra K+ in the extracellular layer is taken up by nearby glial cells; however mild traumatic brain injuries, such as a concussion diminish the effects of this otherwise normal mechanism(Giza & Hoyda, 2001). With no glial cells taking up the extra K+, the extra K+ keep stimulating more nonspecific depolarization, which causes even more glutamate to be released, thus repeating the cycle that leads to an increase of extracellular K+ in the first place(Giza & Hoyda, 2001).

With a huge efflux of extracellular K+, the neuron futilely attempts to restore homeostasis by activating the sodium-potassium pump, which requires a large of amount of ATP (cellular energy) to be made spontaneously (Giza & Hoyda, 2001). Since the brain receives most of its ATP by the oxidative system and by default, this system usually runs at a higher level, the extra ATP must come from another source. The ATP required for this step is derived from the anaerobic breakdown of glucose by the glycolysis mechanism(Giza & Hoyda, 2001).

A concussion, like other brain traumas, impairs oxidative metabolism, which reduces the amount of ATP that is produced by that system. Therefore, there is an increased reliance on glycolysis, for normal ATP production. With the brain profusely relying on glycolysis for its basic energy needs and for the running of the sodium-potassium pump, the normal bi-product of glycolysis, lactate, starts to generate at a higher than normal rate(Giza & Hoyda, 2001). As this is occurring, there is as much as a 50% decrease in the blood supply to the affected neurons caused by the concussion. The lack of blood results in less oxygen and lactate to be removed from the neuron. Lactate then starts to accumulate at a faster rate than normal. This accumulation of lactate can lead to neuronal dysfunction such as acidosis, membrane damage, altered blood brain barrier permeability, and cerebral edema (Giza & Hoyda, 2001).

This increase of energy production and lactate accumulation can last up to 30 minutes, but it is soon followed by a metabolic depression(Giza & Hoyda, 2001). Another ion, Calcium, starts to accumulate as well within hours of the occurrence of the concussion(Giza & Hoyda, 2001). The original efflux of K^+ at the start of the concussion causes NMDA to activate and to create pores, from which Ca^{2+} enters the cell (Giza & Hoyda, 2001). This increase of Ca^{2+} can enter the mitochondria of the neuron, which can lead to a further impairment of oxidative metabolism(Giza & Hoyda, 2001).

Another ion, Magnesium, is affected by a mild traumatic brain injury by causing intracellular levels to drop and to remain low for up to 4 days(Giza & Hoyda, 2001). This impairment of Mg^{2+} can lead to neurocognitive deficits. Pretreatment to restore magnesium levels resulted in improved motor performances in experimental animals. Low levels of Mg^{2+} are associated with impairment of both the glycolytic and oxidative generation of ATP.

Any action taken by the brain to recover its homeostasis or to produce ATP further complicates the problem, since it creates an energy crisis within an environment where the blood supply is compromised. This energy crisis is a likely mechanism for post-concussion vulnerability. The most pressing problem is the accumulation of Ca2+ as this can lead to apoptosis, through a variety of mechanisms such as the over activation of phospholipases, plasmalogenase, calpains, protein kinases, nitric oxide synthase, and endonucleases. However the neuron can still survive. It has been shown that while the influx of Ca2+ increases dramatically, by day 4 Calcium levels drop with no permanent morphological damage(Giza & Hoyda, 2001). Cell death is seen in animal neurons where calcium levels stay elevated for longer periods of time and is seen as a last ditch effort to maintain homeostasis (Giza & Hoyda, 2001).

While there is uncertainty of the biomechanical forces that create a concussion, on-field evaluation of athletes is of the upmost importance for the athlete's health and safety. Athletic trainers and other clinicians need to recognize the symptoms of a concussion so athletes can be taken off the field before any further injury can occur. Numerous researchers from universities and from those involved in the 3rd International Conference of Concussions in sports have documented similar symptoms with athletes in a wide range of concussion cases.

The most immediate symptoms of a concussion are somatic, cognitive, and/or emotional (McCrory, et al., 2009; Paul McCrory, et al., 2013). A variety of symptoms is shown within seconds of receiving a concussion and can last for multiple days. Headaches are one of the most commonly reported symptoms from those who had suffered from a concussion (Eckner & Kutcher, 2010; Majerske et al., 2008; McCrory, et al., 2009). Cognitive symptoms such as a feeling of being in a "fog" or feeling "slowed down" are commonly reported (Eckner & Kutcher, 2010; Majerske, et al., 2008; McCrory, et al., 2009). Being irritable, dazed, confused or sad are typical symptoms to be found in concussed athletes (Eckner & Kutcher, 2010; Majerske, et al., 2008; P McCrory, Johnston, Mohtadi, & al, 2001). Other frequently reported symptoms include numbness and tingling of the extremities, poor concentration, vomiting, retrograde amnesia, poor balance, poor neurocognitive skills and in rare cases loss of consciousness (McCrory, et al., 2009) (Eckner & Kutcher, 2010; Majerske, et al., 2008; McCrory, et al., 2009; Paul McCrory, et al., 2013).

On-field athletic trainers and sport physicians should evaluate athletes on the field in order to recognize the symptoms. Contrary to popular belief, a loss of consciousness is not necessary for concussions, as they are only present in 5% to 10% of cases (Majerske, et al., 2008; McCrory, et al., 2009), therefore making them poor indicators of whether a concussion has occurred. It is recommended that brief neurocognitive batteries that test the attention and memory of the athlete be used to assess the athlete. The most common tools for evaluating concussions are the Standardized Assessment of Concussion (SAC), and Maddocks Equations (Paul McCrory, et al., 2013).

SAC is a quick, easy test that athletic trainers and others can cross-reference in order to evaluate a concussions on the sideline of the field (McCrory, et al., 2009). The tests are meant to challenge the neurocognitive skills of the athlete and include such tests as memorization of numbers and words and saying the days and months in reverse order. A low score could indicate an athlete could be suffering from a concussion if they have some the symptoms that are also associated with concussions (McCrory, et al., 2009).

Retrograde amnesia, or amnesia of past events within hours of the impact, is a less than common symptom of a concussion; however it is still a telltale sign of a concussion. The signs of amnesia can appear in a player in less than 15 minutes after the event. It has been shown that the Maddocks Equations is a very effective sideline tool in evaluating the amnesia (Maddocks, Dickers, & Saling, 1995). Unlike other amnesia tests, which ask athletes simple questions such what day of the week it is, what year is it, and similar questions, the Maddocks equations involve questions about the current situation in which the player finds himself, such as what the score is, what quarter it is, who was their last opponent, who scored last, and similar questions relating to the game. This tool has seen to be much more effective in determining when athletes might have a concussion (Maddocks, et al., 1995).

Perhaps one of the most useful tools for diagnosing a concussion is a computerized neuropsychological test (Broglio, Macciocchi, & Ferrara, 2007a; Eckner & Kutcher, 2010; McCrory, et al., 2009). As stated previously, a neurocognitive deficit is a common symptom of a concussion and the ability to test for these deficits is important in identifying a concussion and when an athlete has recovered(McCrory, et al., 2009). There are numerous neurocognitive tests, with ImPACT being one of the most popular. Despite minor differences all of them contain elements consisting of simple reaction tests, memorization, and other neurocognitive trials to test for the presence of impairment compared to the athlete’s baseline score. A key strength of these tests is that they are able to identify when an athlete could still be suffering from a concussion, even if they report they are asymptomatic(Fazio, Lovell, Pardini, & Collins, 2007). Combined with SAC, balance test, symptom checklist and cognitive testing the highest sensitivity rate that was achieved was 96% (Broglio, Macciocchi, & Ferrara, 2007b).

When athletes have been diagnosed with a concussion they will recover at their own rate, as the neurons heal themselves (Giza & Hoyda, 2001; Majerske, et al., 2008; McCrory, et al., 2009). There is no known medication to specifically deal with a concussion, though medication can be given for the symptoms of the concussion. Each athlete recovers at a different rate, most athletes report being asymptomatic after 5 to 7 days, matching the time frame for how long it takes for the brain to recover metabolically. However it is not uncommon for an athlete to take more time to recover(McCrea & Guskiewicz, 2003; McCrea et al., 2009). When it comes to fully recovering from a concussion there are multiple protocols an athlete can take, as there is no universal protocol. This can be troublesome as different sport medical facilities have their own protocols on when it is safe for an athlete to return to playing, which could endanger an athlete's health. It been highly recommended that an athlete follow an exercise protocol where they return to their sport slowly, keep track of their symptoms, and use a neurocognitive test to check their progress of recovery (Eckner & Kutcher, 2010; McCrory, et al., 2009). A concussed athlete should rest completely and perform no exercise in order to avoid aggravating their symptoms in the first few days after being concussed. (Eckner & Kutcher, 2010; McCrea, et al., 2009; McCrory, et al., 2009). After resting for the necessary time, the athlete should slowly return to exercising. (Eckner & Kutcher, 2010; Eckner, Whitacre, Kirsch, & Richardson, 2009; McCrory, et al., 2009). It is then recommended that as long as the athlete is symptom free that they should first do slow aerobic exercise, then perform skill specific exercises, follow by noncontact practices, and then eventually to full contact practice (McCrory, et al., 2009).

Despite the growing knowledge base surrounding concussions, there is still much more to research that could benefit the athletes' safety in a variety of significant ways. As previously discussed, concussion have a lasting effect on cognitive ability, and as a consequence could potentially lead to further injuries. One of the areas being researched is the effect that a concussion can have on the response time of athletes. Response time is the total amount of time for a response to occur in response to a stimulus. Response time is made up of two different parts; reaction time and movement time.

Reaction time is an important measurement of information-processing speed; commonly defined as the interval of time from a suddenly presented, unanticipated stimulus until the beginning of the response (Schmidt, 1991). Reaction time is normally dependent on three different stages; stimulus identification, response selection, and response programming (Schmidt, 1991). In sport psychology, reaction time is also associated with movement time, which is the amount of time that is required for the correct movement to be made (Schmidt, 1991). The total combined time of reaction time and movement time is known as the response time. Response time has a lot of external validity in sport performances. Some examples includes the cognitive processing involved in agility tasks (Galpin, Li, Lohnes, & Schilling, 2008; Sheppard & Young, 2007). This includes the initiation of movement away from an opponent, or in some instances the avoidance of non-contact muscular skeletal injury (Swanik, Covassin, Stearne, & Schatz, 2007; Taimela et al., 1990).

Typically, reaction time is measured in a variety of ways; different tools of measurements have been used to record reaction and movement time. Essentially the three most commonly used methods of measuring reaction time are by using a variation of a simple, recognition, or choice reaction times tests (Luce, 1986; Welford, 1980). In a simple reaction test, an individual will respond to one stimulus while in a choice reaction test the individual will respond to multiple stimuli. In a recognition reaction test, an individual will respond differently to different stimuli, doing different actions for different stimulus.

Depending on the interest of the researchers, one or more of these types of tests can be used. In a real world task and in the sporting fields, most athletes will react to what would be the equivalent of choice reaction and recognition tests; as multiple stimulus are presented to the athletes, the athlete must recognize them and react accordingly as quickly as possible (Schmidt, 1991; Sheppard & Young, 2007)

Complexity of the test will affect reaction time, with more complicated tests having a longer reaction time and movement time (Henry & Rogers, 1960; Luce, 1986; Mickeviciene, Motiejunaite, Skurvydas, Darbutas, & Karanauskiene, 2008). This is due to the fact that the time for processing takes longer for a more complex reaction test than a simple reaction test(Henry & Rogers, 1960; Luce, 1986). However having a high speed performance in a simple task does not indicate that the athlete will be high performing in a complicated task(Mickeviciene, et al., 2008). Movement time and reaction time are also independent of each other, since a faster movement speed will not be guaranteed because of a faster performance in a simple task (Mickeviciene, et al., 2008). This is due to the fact that reaction time is associated with processing the stimuli, while movement speed depends on the speed of muscle contraction. The total response time will still be affected by a poor performance in either variable. One of the largest influences in reaction time is the number of stimulus that is given to the individual. In choice and recognition tests, reaction time is dependent on the alternatives of stimulus-responses. Choice reaction test is linearly related to the amount of information that has to be processed in order to respond correctly to the various forms of possible stimulus-response alternatives (Hick, 1952); this forms the basis of Hick's law. The increased rate has been shown to be constant in a variety of different research studies, such as in Hyman and Brainerd (Brainard, Irby, Fitts, & Alluisi, 1962; Hyman, 1953). It is one of the most important laws of human performances and implies that choice reaction time increases at a constant rate every time the number of stimulus increases (Hick, 1952; Schmidt, 1991).

Practice and learning effects are usually among the biggest problems when performing a reaction test of any sort. It's been suggested from many different sources that an individual should perform enough practice trials so that the standard deviation is no greater than 10% of the mean time in a simple reaction test, while choice reaction tests has a bigger buffer zone of 15%-20% (Sanders, 1998).

In choice reaction tests that involves testing agility and foot speed of athletes it is important that athletes are familiar with the tools that are being used and the task that is being performed(Bonjour et al., 2011; Galpin, et al., 2008; Hertel, Denegar, Johnson, Hale, & Buckley, 1999; Johnson, Hertel, Olmsted, Denegar, & Putukian, 2002). These researchers have suggested having numerous practice trial days prior to testing to help gather accurate results. The practice effect on response time can be seen in different skills levels of athletes, as more experienced athletes are able to more quickly recognize the movement of opponents (Sheppard & Young, 2007).

Neurologically there can be many factors that can affect reaction time and the movement time of the muscular system. At its core, reaction time is only as fast as the nervous system is able to transfer the stimulus to the brain in order to be processed. Auditory stimulus only take 8-10 ms to reach the brain, visual stimulus takes 20-40 ms (the biggest difference depending on whether it is central vision or peripheral vision), and touch is the slowest at 155 ms (Liukkonen). The differences can be due to a variety of reasons such as the nervous system has different speeds for different sources of signals; muscles averages 119 ms, touch averages 76.2ms, and pain averages 0.61ms (Liukkonen).

Both the arms and legs can be valid methods to use for measuring response time with the arms and legs sharing high reliability with each other. (Chan & Chan, 2009; Simonen, Battie, Videman, & Gibbons, 1995). Shorter people tend to have faster reaction time, due to the shorter distance that signals have to travel (Samaras, 2007). Shorter people might be able to accelerate their body limbs at a faster rate, since acceleration is inversely related to height and therefore decreases with increasing height(Samaras, 2007). Shorter people also have a higher strength to weight ratios. Physics wise, maximum force generated by the body is proportional to the cross-sectional area of each muscle, and since body weight increases faster than cross-sectional area with increasing height, a taller athlete would be less able to move or lift his/her body than a taller individual (Samaras, 2007).

As a result of higher limb acceleration and a higher strength to weight ratio, shorter people tend to be more agile than taller, heavier people. Meaning they can stop, start, and change direction of their movements more quickly, thus increasing their movement time. However other factors must be considered that affect physical performance, such as individual characteristics, percentage of muscle fiber, and psychological factors to name a few (Samaras, 2007). Movement time is therefore affected by a variety of factors that must be considered.

There has been some exploratory research on how BMI might have an effect on reaction time and movement time as well. In a simple computerized reaction time test, those with a higher BMI, were shown to respond slower than those within a healthy BMI (Nikam & Gadkari, 2012; Skurvydas et al., 2009). Females who had a lower BMI were shown to have slower reaction time than those who had a higher, but still within the healthy range of BMI (Nene, Pazare, & Sharma, 2011).

BMI and movement is still an unexplored area in the study of movement. It has been observed casually that athletes in rugby and soccer who perform better on agility tests, tend to have lower body fat percentage (Sheppard & Young, 2007). It been observed that in elite female basketball players that body height and body weights significantly influence the speed of acceleration; those with a lower body weight tend to perform better than their heavier counterparts (Erculj, Bracic, & Jakovljevic, 2011). As previously stated, anthropometric measurements can influence movement (Samaras, 2007). However, the effects that BMI might possibly have on both reaction time and movement time (such as agility and change-of-direction) is still an unexplored area of research that should be further investigated.

Age and gender are two of the biggest influences affecting reaction time. In a longitudinal study done on over 1200 participants, reaction slowed down after the age of 20 (Fozard, Vercruyssen, Reynolds, Hancock, & Quilter, 1994). In a simple reaction test, response slowed down on average by 0.5 milliseconds per year (Fozard, et al., 1994). In a study done for the United Kingdom Health and Lifestyle survey, over 7,500 individuals were tested. The results showed that simple reaction time did not slow down significantly until the age of 50, however in a choice reaction test, there was slowing down throughout the adult ages (Der & Deary, 2006). Both of these studies showed significant differences between males and females in all ages and testing methods (Der & Deary, 2006; Fozard, et al., 1994).

Response time, as well as reaction time and movement time, are severely impacted by concussions and have been seen to have a lingering effect even when the athlete has been reported to be asymptomatic (Eckner & Kutcher, 2010; Eckner, et al., 2009; McCrory, et al., 2009). Processing speed can be reduced in athletes who have suffered multiple concussions, having a negative effect on response time. Therefore the use of reaction time and movement time could have potential usage in the evaluation of concussions, since there are some disadvantages in current models of return-to-play protocols.

One of the problems is the under reporting of symptoms. Even though an athlete might no longer report having any symptoms, their neurocognitive test scores might still not have not returned to their baseline scores (Fazio, et al., 2007) Even combining different test batteries, we still only get a sensitivity rate of 96%(Broglio, et al., 2007b), which mean that nearly 10% of players are not being detected with a concussion and returning too early to the field. Multiplied by the predicted number of concussions that occur each year in athletics of 1.8 million to 3.6 million athletes (Langlois, Rutland-Brown, & Wald, 2006), that leaves an estimated 72,000 to 144,000 athletes who could be returning to play too soon and therefore be in danger of risking another concussion. This puts too many athletes at risk and is a problem that should be addressed.

Some of the possible solutions could be to increase the sensitivity of current tests or to add tests that could help increase the overall sensitivity rate, whether or not the athletes are symptomatic. It been suggested that testing procedures that could better test an athlete in a more complex fashion could better diagnose the recovery of the patient (Catena, Donkelaar, & Chou, 2007; Tonya Parker, Osternig, & Donkelaar, 2007). One of the best possible solutions could be from adding a reaction time test that is more likely to mimic field conditions

Most neuropsychological tests already include trials to test the reaction time, however these trials are very limited. Most of the trials are simple reaction tests that just require mouse clicking when they observe a particular stimulus on the screen or involve the catching of a drop-ruler(Broglio, et al., 2007b; Eckner, Kutcher, & Broglio, 2013; Eckner, Kutcher, & Richardson, 2010; McCrory, et al., 2009). These tests are limited in that they do not realistically test the kind of reaction that might be seen on the field.

In a 2007 study, Catena, looked at the effects that concussions had on gait, balance, and the sways of the center of mass in concussed individuals (Catena, van Donkelaar, & Chou, 2007). He tested for gait stability under different circumstances, such as simply walking across the testing room or while performing a concurrent task; either a question and answer task or a simple reaction time task. In general, the concussed athletes adopted a slower, more conservative gait, similar to previous studies (as noted by Catena) (Chou, Kaufman, Walker-Rabatin, Brey, & Basford, 2004; TM Parker, Osternig, van Donkelaar, & Chou, 2005). In those studies, subjects had their reaction time tested while walking. The subjects would "hear an audible cue when the photocell beam was broken and then respond by pressing a button on the handheld trigger" (Catena, van Donkelaar, et al., 2007) and the cue was randomly dispersed.

Also interesting to observe were the effects that the concussions had on the reaction time of subjects while they were walking. All of the participants, both experimental and control had a similar reaction time, though the concussed group did have higher reaction time variability. It is believed this is caused by intrasubject differences in concussive episodes. Oddly enough, the inclusion of the reaction time task led to a less conservative gait, than when performing a cognitive task in gait for concussed individuals. A multi-response reaction time or a choice reaction time task was recommended to determine whether the effects of the task are related and/or difficulty related.

Testing purely response time in athletes who have suffered a concussion is still a relatively unexplored area, since few researchers have dedicated their resources to just studying this one particular trait. However, limited the research might be, it has the potential in helping to evaluate athletes, whether they suffered a concussion or have recovered from one.

In 2001 Warden et al. published a study where he tested military cadets on a computerized simple reaction test, in which the cadet only had to respond to one stimulus. All the cadets performed baseline testing, but only 14 cadets received a concussion during physical education boxing. He tested the 14 cadets 1 hour post injury and again after 4 days when they returned to full participation. His results showed that the cadet's reaction times were significantly slower when compared to baseline, one-hour post injury. When tested again 4 days post-concussion, their performance scores were still significantly slower, even when the cadets reported being asymptomatic and were allowed to return to playing.

In two more recent investigations, Eckner et al. (2010 & 2013) have done a series of studies to help evaluate a clinical tool developed for possible use on the field. A major disadvantage of current neuropsychological tests is that they are limited in being used for initial field testing, due to a lack of resources or simply not being available for athletic trainers to use. The studies done by Eckner et al. (2010 & 2013) may provide a solution to the problems of computerized tests. Since his sample test is easy enough for all athletic trainers and clinicians to administer without a lot of training, is accessible for use by all, and is inexpensive since it requires few materials.

Eckner's reaction test is a simple drop ruler test, in which a trained clinician would drop a 1.3meter ruler wrapped in friction tape and embedded in a weighted rubber disk for stability purposes. When the clinician drops it, the participant would catch it as quickly as (s) he could. How far the ruler fell before the participant would catch it would be an indication of response time. Also considered was the fact that athletes seemed more enthusiastic about performing the test. This can help to gather more reliable sources of information and also to deal with the problem of athletes intentionally flunking the tests. This has been proven to be a reliable and valid measurement in a previous study in which healthy individuals did the drop ruler test. (Eckner, et al., 2009).

In the pilot study, the objective of Eckner et al. (2013) was to see if the drop ruler test could also be a valid test that could be used on athletes who had a concussion. To make the comparison of the reaction times, he tested 94 healthy Division 1 football players on his test and then on the computerized Cog State Sport neuropsychological test (Eckner, et al., 2010). The Cog State Sport reaction test is a simple reaction test, in which there was only one stimulus to which to respond. In this case, the athlete would have to press a button when a playing card was shown on the computer.

The test indicated there was a possible positive correlation between the two tests. An interesting point was that the test results were more consistent for the drop rule test based on two points; one, that the drop ruler test score had less variability regardless of the number of times it was repeated; and two, . The that athletes who had to repeat the Cog State Sport reaction test usually had different results on their test retakes (Eckner, et al., 2010). It was suggested that one reason that the athletes performed better on the drop ruler test, was that the athletes were more motivated, since they were able to view their progress in real time (Eckner, et al., 2010). This avoids one of the major problems of computerized testing, in which there is poor participation on the part of the test taker (Broglio, et al., 2007b).

Another major strength of the drop ruler test is its ease, availability and simplicity as a means of gathering baseline data and the fact that it can be added to an athletic trainers' bag of tools when evaluating a concussion. The follow-up study done shows that this was a reliable and sensitive tool for testing concussed participants (Eckner, et al., 2013). This study showed that perhaps this test could be used to test recently concussed athletes, though the certainty of testing individuals afterwards is unsure.

A common trait that all reaction time tests share is that they are nearly all simple reaction tests, in which there is only one stimulus requiring response by the participants. This differs from the stimuli that an athlete finds in his/her sport. Many sports require split second decisions on movements to be made, whether it is deciding on where to travel, catching, running, hitting, or numerous other sport-related actions. This decision is made on the basis of cognitive thinking and reacting as quickly as possible to those stimuli. A delay in this decision, even a hesitation of a hundredth of a second can impact an athlete's performance and could lead to further injury.

According to Hick's Law when more stimuli are available to an individual, it will take longer it for that individual to cognitively process that information and to respond accordingly (Hick, 1952). So naturally, an athlete will respond faster when using a simple reaction test, rather than another reaction test. However an athlete who has had a concussion will suffer from an impairment in their neurocognitive abilities and will have a slower processing time (Gardner, Shores, & Batchelor, 2010; McCrory, et al., 2009). This could be a possible weakness of the simple reaction test that is popularly used, since it is very limited in actually testing the athlete's neurocognitive abilities. So in accordance to Hick's Law, using a reaction test with multiple stimuli is a much better way of testing the cognitive skills of the injured athlete (Hick, 1952). Agility tasks that require choice reaction tests have been suggested in the evaluation of concussions.

In a 1999 study, Hershel performed a study in the evaluation of the Cybex Reactor, at the time a commercially available agility trainer (Hertel, et al., 1999). Similar to the "dot drills" that are commonly used in athletic training, the Cybex consisted of dot drills where an athlete would react to the light stimulus according to a video screen that was connected to the personal computer running the software. An athlete could move to 14 different dots, thus providing a choice reaction test. The dynamic movements involved were more similar to sport movements than those found in other reaction/response time testing.

The device was tested for reliability and validity; however a possible limitation of the Cybex device was that of learning effects and the fact that improvements in response time could be from motor learning. Hertel suggested that at minimum, 4 practice trials be given to help record accurate results. He also suggested that training should be done on the device every 6 weeks in order to minimize learning effects as well. With both of these factors, it gives the athletes enough practice trials to familiarize themselves with the task, so that improvement could be seen from training rather than from a learning effect.

Besides measuring performance, Hertel discussed the Cybex device's potential usage in the evaluation of sport injuries. Hershel explained that the Cybex reactor could be used in the evaluation of sport injuries, concussions being one of them. He suggested that exploratory research should be done in order to evaluate its potential in identifying any lingering effects from injuries.

In 2002, P.D. Johnson did just that and used the Cybex Reactor assessed by Hershel for the evaluation of concussions(Johnson, et al., 2002). Johnson was able to baseline test 84 athletes before the start of the season using the same testing protocol that was done with the previous study done by Hertel (Hertel, et al., 1999). Of the 84 tested, 9 athletes (5 females and 4 males) suffered a concussion. When the athlete received a concussion, they were brought in to the lab to take the same reaction test on Cybex Rector as performed previously. A control group was formed to make comparisons with the concussed athletes by matching them with healthy athletes based on sport and gender. He tested the experimental concussed groups on Day 1, Day 3, Day 5, and Day 10 from the occurrence of the concussion and repeated the same testing pattern for the control group.

Johnson was not able to find any significant differences in response time between the healthy control group and the concussed experimental group. The only difference came from 2 outliers, who reported to have more severe symptoms than the others during the course of the study. However the methodology was significantly flawed in that it was not a true choice reaction test. While dynamic movement was involved, cognitive processing did not play a significant role. Johnson explained that the exact same sequence trial was used every time the athlete performed a test, thus severely limiting the cognitive processing involved in response time. This instead made the testing more of motor learning study, as both groups made significant improvements in the time to complete the task throughout the study. If a true random choice test was used, one might be able to find different results from this study. While Johnson suggested that the study should be repeated with a random choice reaction tests, to the author's knowledge, no other attempts have been made.

Based on the suggestion of Johnson at attempting to do another study, the agility trainer Quickboard could be used. QuickBoard like other computerized agility trainers was developed to help trained athletes on their sport performance and has proven to be a reliable and valid tool for measuring reaction time when using healthy, but not non-agility trained athletes (Galpin, et al., 2008). QuickBoard is composed of a black square mat with 5 pressure sensors in the shape of circles. The circles are located in the corners of the mat and in the center of the mat. Connected to the mat is a 10-inch touch screen tablet with the QuickBoard program, which provides a visual stimulus that tells the athletes on which circle to step.

The QuickBoard design has advantages that can make it a valid tool for testing an athlete who has a concussion. Its main strength is that is able to provide multiple stimuli which is better able to test the processing time of the athlete than a simple reaction test, according to Hick’s Law (Brainard, et al., 1962; Galpin, et al., 2008; Hick, 1952; Hyman, 1953). Another advantage is the fact that there is more dynamic movement involved in the testing of the response time. This provides a more sport-like environment that most athletes are accustomed to and could possibly make the test more valid as other researchers have suggested a need to make the testing more difficult (Catena, van Donkelaar, et al., 2007; Tonya Parker, et al., 2007). Another possible advantage is that the athlete might feel more motivated to do a QuickBoard test, making it more likely for the athlete to fully participate in the tests.

Despite these strengths, the main weakness of the QuickBoard is its uncertainty, since it has never been tested before for concussion purposes, so it is not known if it's sensitive enough for detecting any impairment caused by a concussion. Another possible problem is the movement requires completing the necessary tests. Studies have found heavy exercise can aggravate the symptoms that the athlete might be experiencing after a concussion (McCrory, et al., 2009), therefore limiting movement time if the athlete is feeling symptomatic.

In conclusion, a concussion is a complex mild traumatic injury that affects many athletes. The knowledge base for concussion has grown enormously in the past decade and we are better able to protect athletes thanks to the combined efforts of many researchers and health care providers. There is potential in using a response time test that mimics sports movement, however there are still more challenges ahead and questions that need to be answered.

REFERENCES

1. Bonjour, J., Bringard, A. l., Antonutto, G., Capelli, C., Linnarsson, D., Pendergast, D., & Ferretti, G. (2011). Effects of acceleration in the G axis on human cardiopulmonary responses to exercise. [Article]. *European Journal of Applied Physiology, 111*(12), 2907-2917. doi: 10.1007/s00421-011-1917-0
2. Brainard, R., Irby, T., Fitts, P., & Alluisi, E. (1962). Some variables influencing the rate of gain of Infomation. *Journal of Experimental Psychology, 63*(2), 105-110.
3. Broglio, S., Macciocchi, S., & Ferrara, M. (2007a). Neurocognitive performance of concussed athletes when symptom free. *Journal of Athletic Training, 42*(4), 504-508.
4. Broglio, S., Macciocchi, S., & Ferrara, M. (2007b). Sensitivity of the concussion assessment battery. *Neurosurgery, 60*(6), 1050-1058.
5. Brolinson, P., Manoogian, S., McNeely, D., Goforth, M., Greenwald, R., & Duma, S. (2006). Analysis of linear head accelerations from collegiate football impacts. *Current Sport Medicine Reports, 5*, 23-28.
6. Catena, R., Donkelaar, P. v., & Chou, L.-S. (2007). Altered balance control following concussion is better detected with an attention test during gait. *Gait & Posture*, 406-411.
7. Catena, R., van Donkelaar, P., & Chou, L.-S. (2007). Cognitive task effects on gait stability following concussion. *Journal of Experimental Brain Research*(176), 23-31.
8. Chan, K., & Chan, A. (2009). Spatial stimulus-response (S-R) compability for foot controls with visual display. *International Journal of Industrial Ergonomics, 39*, 396-402.
9. Chou, L., Kaufman, K., Walker-Rabatin, A., Brey, R., & Basford, J. (2004). Dynamic instability during obstacle crossing following traumatic brain injury. *Gait & Posture, 20*, 245-254.
10. Der, G., & Deary, I. (2006). Age and sex dfferences in reaction time in adulthood: results from the united kingdom health and lifestyle survey. *Psychology and Aging, 21*(1), 62-73.
11. Eckner, J., & Kutcher, J. (2010). Concussion symptom scales and sideline assessment tools: A critical literature update. *Current Sport Medicine Reports, 9*(1), 8-15.
12. Eckner, J., Kutcher, J., & Broglio, S. (2013). Effect of sport-related concussion on clinically measured simple reaction time. *British Journal of Sports Medicine, Published online first*(10.1136/bjsports-2012-091579).
13. Eckner, J., Kutcher, J., & Richardson, J. (2010). Pilot evalution of a novel clinical test of reaction time in national collegiate athletic association division I football players. *Journal of Athletic Training, 45*(4), 327-332.
14. Eckner, J., Whitacre, R., Kirsch, N., & Richardson, J. (2009). Evaluating a clinical measure of reaction time: an observational study. *Percept Mot Skills, 3*, 717-720.
15. Erculj, F., Bracic, M., & Jakovljevic, S. (2011). The level of Speed and Agility of Different Types of Elite Female Basketball Players. *Physical Education and Sport, 9*(3), 283-293.

16. Fazio, V., Lovell, M., Pardini, J., & Collins, M. (2007). The relation between post concussion symptoms and neurocognitive performance in concussed athletes. *NeuroReahabilitation, 22*, 207-216.
17. Fozard, J., Vercruyssen, M., Reynolds, S., Hancock, P., & Quilter, R. (1994). Age differences and changes in reaction time: The Baltimore longitudinal study of aging. *Journal of Gerontology, 49*(4), 179-189.
18. Galpin, A., Li, Y., Lohnes, C. A., & Schilling, B. K. (2008). A 4-week choice foot speed and choice reaction training program improve agility in previously non-agility trained, but active men and women. *Journal of Strength and Conditioning Research, 22*(6), 1901-1907.
19. Gardner, A., Shores, A., & Batchelor, J. (2010). Reduced processing speed in rugby union players with three or more previous injury. *Archives of Clinical Neuropsychology, 25*(3), 174-181.
20. Giza, C., & Hoyda, D. (2001). The Neurometabolic cascade of concussions. *Journal of Athletic Training, 36*(3), 228-235.
21. Guskiewicz, K., Mihalik, J., Shankar, V., Marshall, S., Crowell, D., Oliaro, S., . . . Hooker, D. (2007). Measurement of head impacts in collegiate football players: relationship between head impact biomechanical and acute clinical outcome after concussion. *Neurosurgery, 61*(6), 1244-1253.
22. Henry, F., & Rogers, D. (1960). increased response latency for complicated movements and a "Memory Drum" theory of neuromotor reaction. *Research Quarterly, 31*(621-652).
23. Hertel, J., Denegar, C., Johnson, P., Hale, S., & Buckley, W. (1999). Reliability of the Cybex Reactor in the assessment of an agility task. *Journal of Sport Rehabilitation, 8*, 24-31.
24. Hick, W. (1952). On the rate of gain of information. *Quarterly Journal of Experimental Psychology, 4*(1), 11-26.
25. Hyman, R. (1953). Stimulus Information as a determinant of reaction time. *Journal of Experimental Psychology, 45*, 188-196.
26. Johnson, P., Hertel, J., Olmsted, L., Denegar, C., & Putukian, M. (2002). Effects of mild brain injury on an instrumental agility task. *Clinical Journal of Sport Medicine, 12*(1), 12-17.
27. Langlois, J., Rutland-Brown, W., & Wald, M. (2006). The epidemiology and impact of traumatic brain injury. *Journal of Head Trauma Rehabilitation, 21*(5), 375-378.
28. Liukkonen, T. Human reaction times as a response to delays in control systems., from Measurepolis http://www.measurepolis.fi/alma/ALMA%20Human%20Reaction%20Times%20as%20a%20Response%20to%20Delays%20in%20Control%20Systems.pdf
29. Luce, R. (1986). *Response time: Their role in inferring elementary mental organzation.* New York: Oxford University.
30. Maddocks, D., Dickers, G., & Saling, M. (1995). The assesment of orientation following concussion in athletes. *Clinical Journal of Sport Medicine, 5*(1), 32-35.
31. Majerske, C., Mihalik, J., Ren, D., Collins, M., Reddy, C., Lovell, M., & Wagner, A. (2008). Concussion in sports: postconcussive activity levels, symptoms, and neurocognitve performance. *Journal of Athletic Training, 43*(3), 265-274.
32. McCaffrey, M., Mihalik, J., Crowell, D., Shields, E., & Guskiewicz, K. (2007). Measurement of head impacts in collegiate footplayers: clinical measures of concussion after high and low magnitude impacts. *Neurosurgery-online, 61*(6), 1236-1243.

33. McCrea, M., & Guskiewicz, K. (2003). Acute effects and recovery time following concussion in collegiate football players. *Journal of the American Medical Association, 290*(19), 2556-2563.
34. McCrea, M., Guskiewicz, K., Randolph, C., Barr, W., Hammeke, T., & Kelly, J. (2009). Effects of a symptom free waiting period on clinical outcome and risk of reinjury after sport-related concussion. *Neurosurgery, 65*(5), 876-883.
35. McCrory, Meeuwisse, W., ..., & Cantu, R. (2009). Concensus Statement on Concussion in sport: The 3rd International Conference on Concussion in sport, held in Zurich, November 2008. *Journal of Clinical Neuroscience, 16*, 755-763.
36. McCrory, P., Johnston, K., Mohtadi, N., & al, e. (2001). Evidence-based review of sport-related concussion: Basic Science. *Clin J Sports Med, 11*, 160-165.
37. McCrory, P., Meeuwisse, W., Aubry, M., Cantu, B., & Dvorak, J. (2013). Concensus statement on concussion in sport: The 4th international conference on concussion in sport held in Zurich, November 2012. *British Journal of Sports Medicine, 47*, 250-258.
38. Mickeviciene, D., Motiejunaite, K., Skurvydas, A., Darbutas, T., & Karanauskiene, D. (2008). How do reaction time and movement speed depend on the complexity of the task. *Biomedicinos Mokslai, 2*(69), 57-62.
39. Mihalik, J., Bell, D., Marshall, S., & Guskiewicks, K. (2007). Measurement of head impacts in collegiate football players: an investigation of positional and event-type differences. *Neurosurgery, 64*(4), 719-725.
40. Nene, A., Pazare, P., & Sharma, K. (2011). A study of relation between body mass index and simple reaction time in healthy young females. *Indian Journal of Physiology Pharmacology, 55*(3), 288-291.
41. Nikam, L., & Gadkari, J. (2012). Effect of age, gender, and body mass index on visual and audittory reaction times in indian population. . *Indian Journal of Physiology Pharmacology, 56*(1), 94-99.
42. Parker, T., Osternig, L., & Donkelaar, P. v. (2007). Recovery of cognitive and dynamic motor function following concussion. *British Journal of Sports Medicine, 41*, 868-873.
43. Parker, T., Osternig, L., van Donkelaar, P., & Chou, L. (2005). The effect of divided attention on gait stability following concussion. *Clin Biomech, 20*, 389-395.
44. Pellman, E., Viano, D., Tucker, A., & Casson, I. (2003). Concussion in professional football: location and direction of helmet impacts-Part 2. *Neurosurgery, 53*(6), 1328-1340.
45. Samaras, T. (Ed.). (2007). *Human body sIze and the laws of scaling.* New York: Nova Science Publishers.
46. Sanders, A. (1998). *Elements of human performance: reaction processes and attention in human skill.* Mahwah, New Jersey: Lawrence Erlbaum Associates.
47. Schmidt, R. (1991). *Motor learning and performance*. Champaign, IL: Human Kinetics.
48. Sheppard, J., & Young, W. (2007). Agility literature review: Classifications, training, and testing. *Journal of Sports Science, 24*(9), 919-932.
49. Simonen, R., Battie, M., Videman, T., & Gibbons, L. (1995). Comparison of foot and hand reaction times among men: A methodological study using simple and multiple-choice repeated measurements. *Perceptual and Motor Skill, 80*, 1243-1249.
50. Skurvydas, A., Gutnik, B., Zuoza, A., Nash, D., Zuoziene, I., & Mickeviciene, D. (2009). Relationship between simple reaction time and body mass index *Journal of Comparative Human Biology, 60*, 77-85.

51. Stefan Duma, Manoogian, S., Bussone, W., Brolinson, P., Goforth, M., Donnewerth, J., . . . Crisco, J. (2005). Analysis of real-time head accelerations in collegiate football players. *Clinical Journal of Sport Medicine*, *15*, 3-8.
52. Swanik, C., Covassin, T., Stearne, D., & Schatz, P. (2007). The relationship between neurocognitive function and noncontact anterior cruciate ligament injuries. *American Journal of Sports Medicine*, *35*(6), 944-949.
53. Taimela, S., Osterman, K., Kujala, U., Lehto, M., Korhonen, T., & Alaranta, H. (1990). Motor ability and personality with reference to soccer injuries. *Journal of Sports Medicine and Physical Fitness*, *30*, 194-201.
54. Welford, A. T. (Ed.). (1980). *Choice Reaction Time: Basic Concepts. In A.T.* . New York: Academic Press.

APPENDIX C

TABLES AND FIGURES

TABLE 1. Participant *demographics and concussion history*

Group	***Age(yrs)***	***Weight (kg)***	***Height (cm)***	***Prior Concussion (n)***
RRSA	20.12± 1.64	66.33± 18.69	165.87± 9.49	0. 25± 0.46
HSA	20.75± 1.28	68.29± 20.76	169.75± 9.67	0.37± 0.75

Table 2 Evidence-Based Cantu Grading Systems for Concussion

Grade 1 (mild)	No loss of consciousness; posttraumatic amnesia* or post-concussion signs or symptoms lasting less than 30 minutes.
Grade 2 (moderate)	Loss of consciousness less than 1 minutes; posttraumatic amnesia* or post-concussion signs or symptoms lasting longer than 30 minutes but less than 24 hours
Grade 3 (severe)	Loss of consciousness lasting more than 1 minutes or posttraumatic amnesia* lasting longer 24 hours; post-concussion signs or symptoms lasting longer than 7 days.

* Retrograde and anterograde

TABLE 3. *Participant choice response time task result*

Group	***N***	***Time (s)***
RRSA	8	0.68± 0.067
HSA	8	0.70± 0.068

TABLE 4. *Student-Athlete continuous choice response time task result*

Group	***N***	***Time (s)***	***Errors***
RRSA	8	21.63 ± 2.46	0.75±1.035
HSA	8	20.86 ± 2.92	0.87 ± 0.99

Continuous Choice Response Time Task

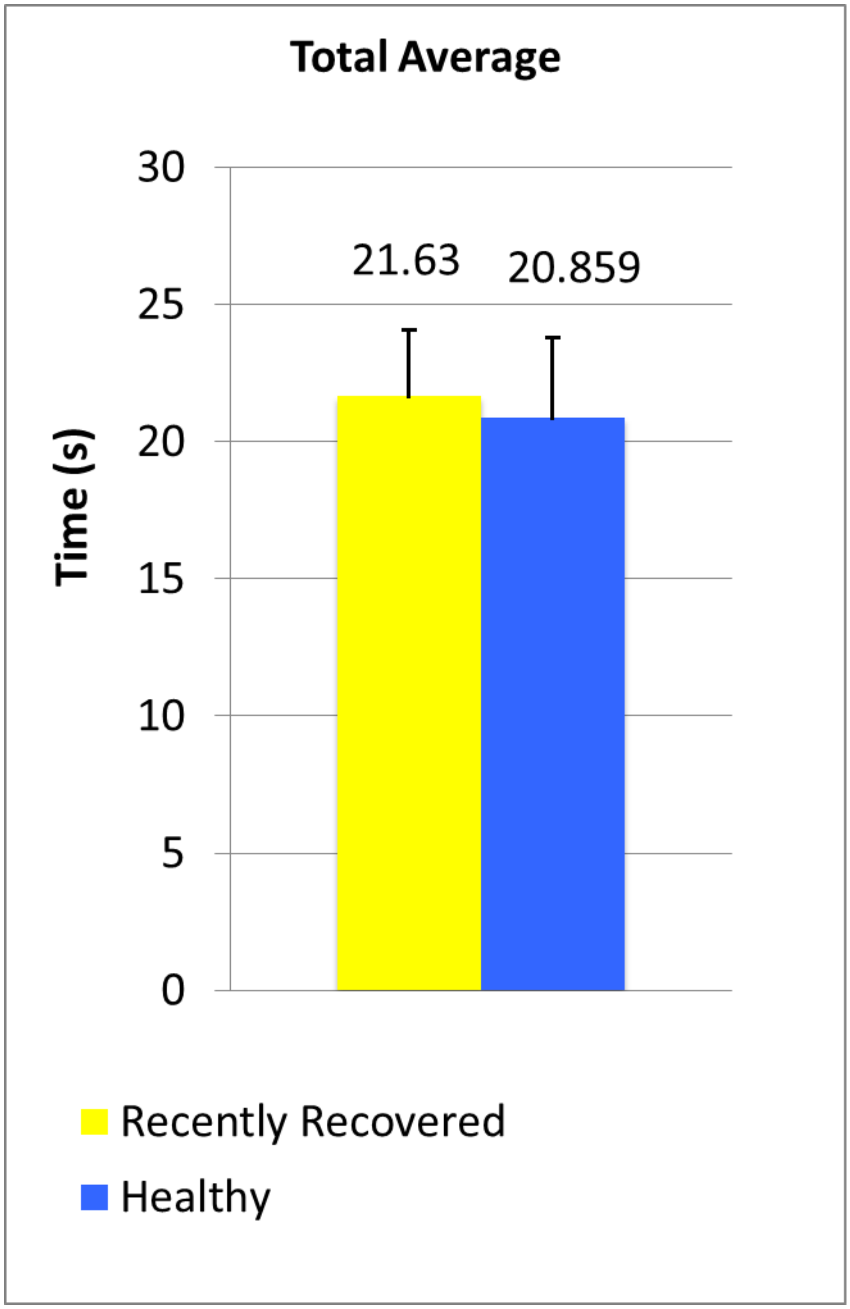

Figure 1. Continuous choice response time group average. This figure shows the averages of the RRSA and HSA.

Continuous Choice Response Time Task

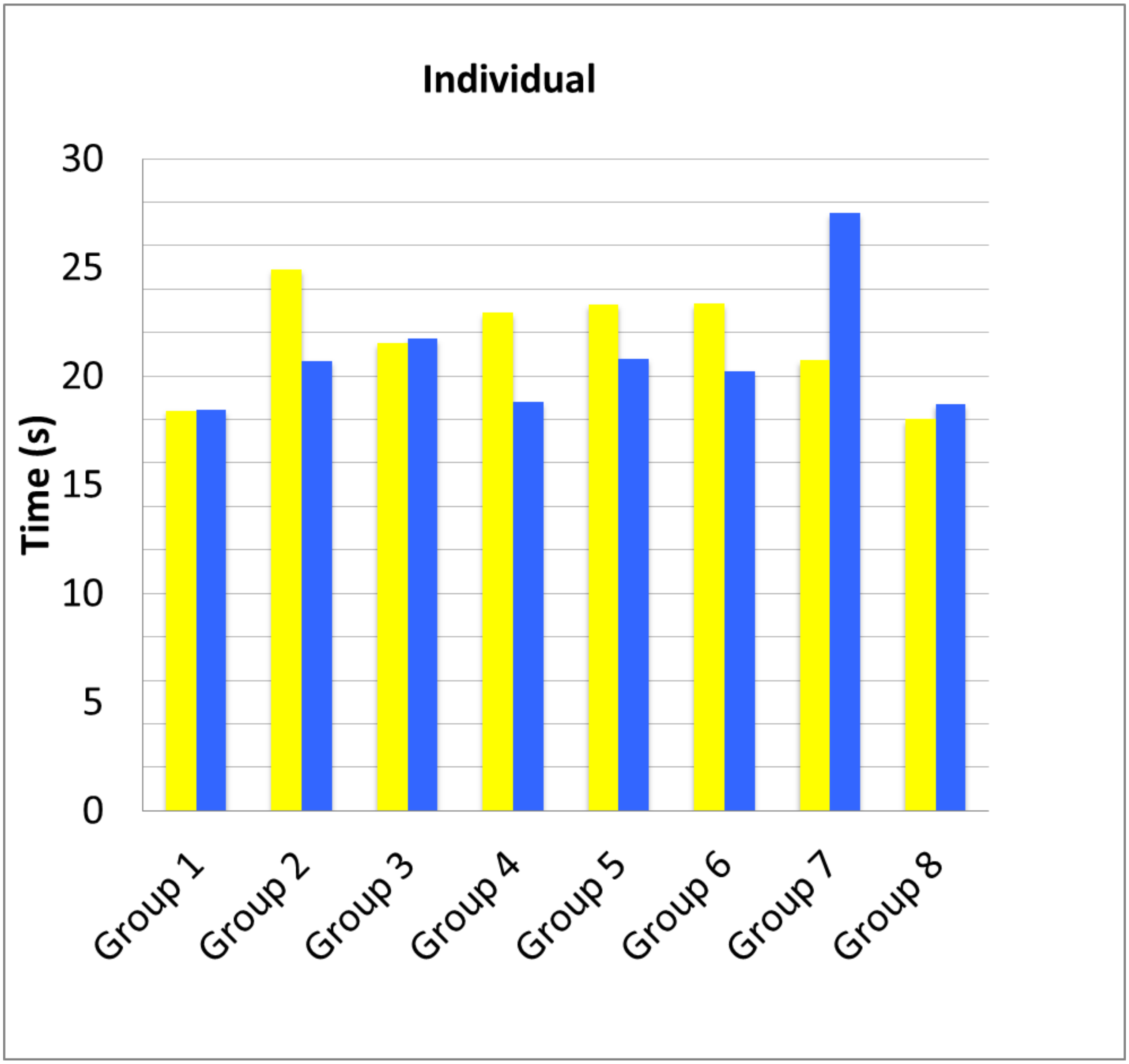

Figure 2. Individual continuous choice response time. This figure shows the individual time of each RRSA and HSA.

Delay Choice Response Time Task

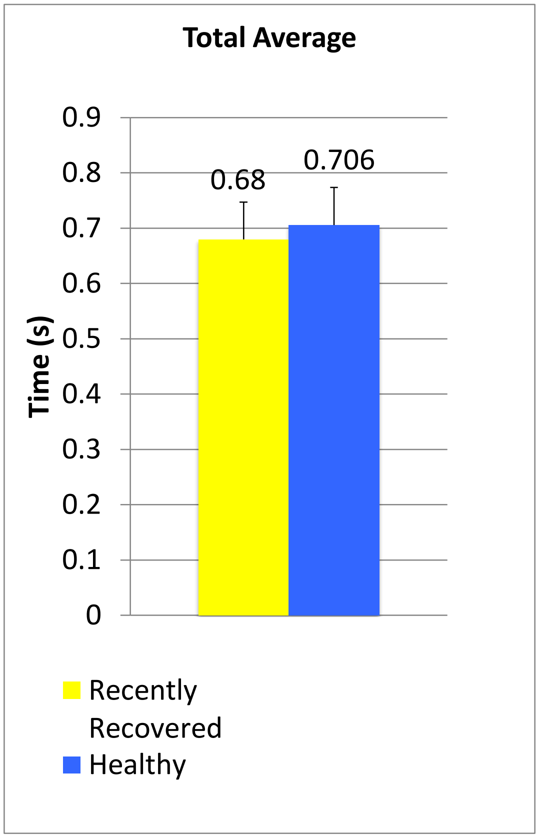

Figure 3. Delayed choice response time group average. This figure shows the averages of the RRSA and HSA.

Delay Choice Response Time Task

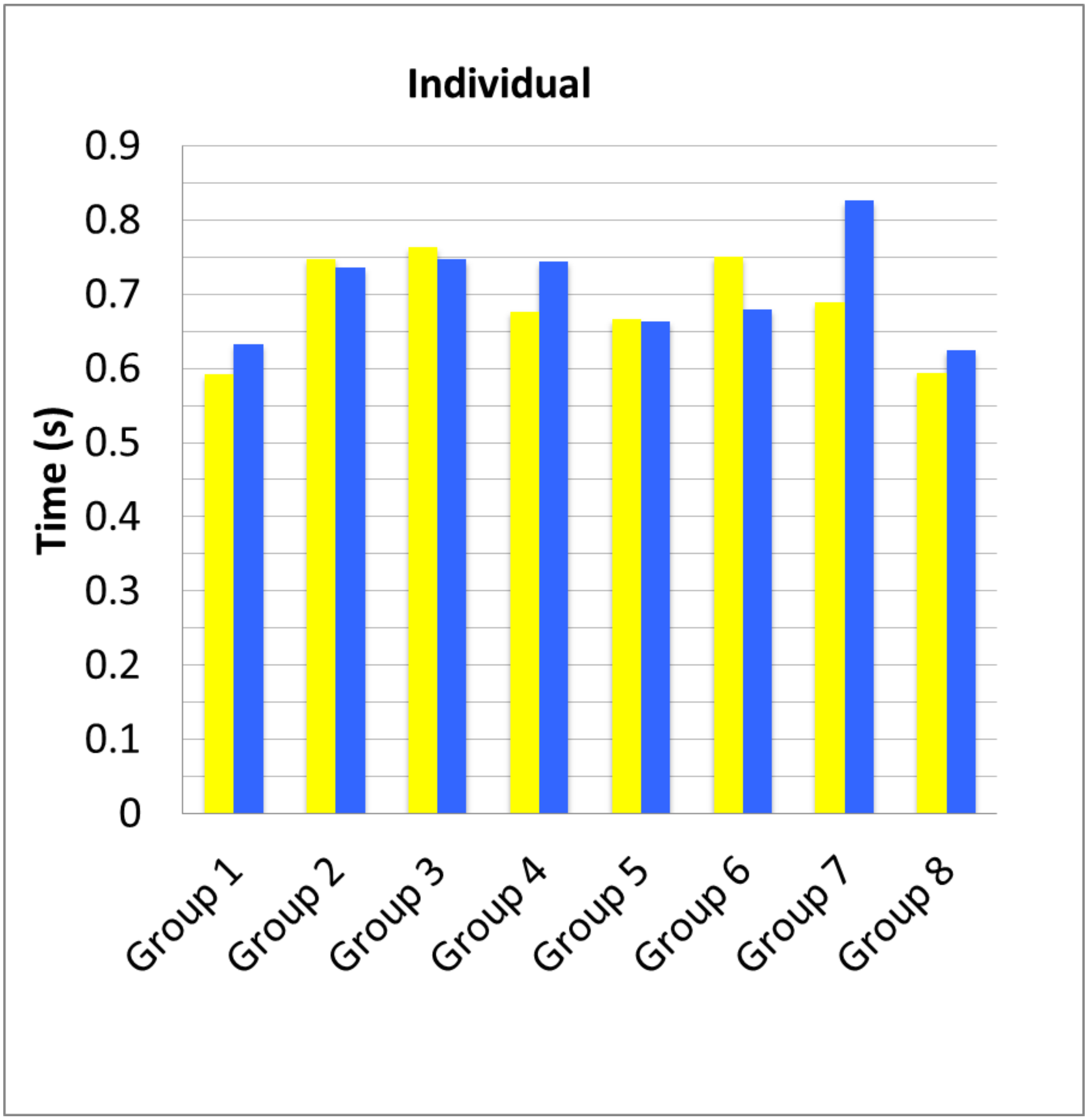

Figure 4. Delayed choice response time individual times. This figures shows the individual times of each RRSA and the HSA

APPENDIX D

CONSENT FORM & HEALTH QUESTIONNAIRE

CONSENT TO ACT AS A SUBJECT IN AN EXPERIMENTAL STUDY

1. The Use of Computerized Agility Trainers for Detecting Reaction Time Impairment in Athletes Who Have Recently Recovered from a Concussion.

Investigator's Name: Tiffen G. Tapia-Lovler Phone: (352)-871-1500

Participant's Name: _____________________ Date: ______________

Data Collection Location: Biomechanical Laboratory, Georgia Southern University Campus

2. Purpose of the Study: The main purpose of the lab is to find the effects of concussions could have on reaction time on athletes. We will be using an electronic agility trainer to record reaction time that involves dynamic movement of the legs. There will be approximately 20-40 subjects in this study. The results of this study may benefit health care professionals in the treatment of sport-related concussion.

3. You are being asked to participate in this study because you are an adult student-athlete at Georgia Southern University who has recently recovered from a concussion or a healthy student-athlete. You also have no history of any injuries to the lower extremities that affect quick and sudden movements.

If you agree to participate in this study you will be asked to attend one testing session that will last about 20 minutes. During the study you will be asked to perform reaction times using a computerize agility trainer that requires quick and sudden movements.

During the session your reaction time will be tested using a computerized agility trainer. The device consists of two main pieces of equipment: an electronic board on which you will step on and a tablet that connects to the board. The tests protocols will require quick and sudden movement of the lower body and cognitive skills involved in reaction time. Your reaction time and accuracy will be recorded.

4. There is a mild risk assumed during testing and is similar to what you would find in common agility training techniques found in many sports. The position of your body will be kept within the mat of the board and will require fast, single step movement.

There is also the rare possibility that a physical injury or latent illness may become evident from exercise. This possibility of injury is minimized by assessments of my physical condition prior to participation in this project.

I understand that medical care is available in the event of injury resulting from research but that neither financial compensation nor free medical treatment is provided. You also understand that you're not waiving any rights that you may have against the University for injury resulting from negligence of the University or investigators. Should medical care be required, you may contact Health Services at (912) - 478- 5641.

5. I understand that I will likely receive no direct benefit for participating in this study, however I will be provided with my results, if I so request. The result of this study may be used to assist health care professionals in the treatment of sport-related concussions.

6. I understand that all data concerning myself will be kept confidential and available only upon my written request to Tiffen G. Tapia-Lovler. I understand that any information about my records will be handled in a confidential (private) manner consistent with medical records. A case number will indicate my identity on all records. I will not be specifically identified in any publications of research results. However, in unusual cases my research records may be inspected appropriate government agencies or released to an order from a court of law. All information and research records will be kept for a period of 3 years after the termination of this study.

7. I have the right to ask questions and have those questions answered. If you have questions about this study, please contact Tiffen G. Tapia-Lovler at (352)-871-1500 or the researcher's faculty advisor, Barry A. Munkasy, Ph.D. (912)-681-0985. For questions concerning your rights as a research participant, contact Georgia Southern University Office of Research Services and Sponsored Programs at 912-478-0843.

8. I will not receive compensation for my participation in this project. I will be responsible for no additional cost for my participation in this project.

9. I understand that I do not have to participate in this study and that my decision to participate is entirely voluntarily. I can choose to end my participation by informing the primary researcher Tiffen G. Tapia-Lovler or by telling any other investigator.

10. If I choose to terminate my participation in this study at any time, I can without prejudice to future care or any possible reimbursement of expenses, compensation, employment status, or course grade except provided herein, ant that owning to the scientific nature of the study, the researcher may in his absolute discretion terminate the procedure and/or investigation at any time.

11. This study does not involve deception of any kind.

12. You must be 18 years of age or older to consent to participate in this research study. You certify that you have read the preceding information, or it has been read to me and you understand its content. If you consent to participate in this research study and to the terms above, please sign your name and indicate the date below.

You will be given a copy of this consent form to keep for your records. This project has been reviewed and approved by the GSU Institutional Review Board under tracking number H1388.

Title of Project: The Use of Computerized Agility Trainers for Detecting Reaction Time Impairment in Recently Concussed Athletes.
Principal Investigator: Tiffen G. Tapia-Lovler, (352)-871-1500, tt02106@georgiasouthern.edu

Faculty Advisor: Barry Munkasy Ph.D., (912)-478-0985, bmunkasy@georgiasouthern.edu

_______________________________________ ______________________

Participant Signature Date

I, the undersigned, verify that the above informed consent procedure has been followed.

_______________________________________ ______________________

Investigator Signature Date

Activity & Health History Questionnaire
Georgia Southern University

1. Demographic Data

(1) Age: ____________________ (2) Gender: _______________

(3) Year in School: ______Freshman ______Sophomore ___Junior

______Senior ______ 5th Year

2. Injury History

1. (1) When did you suffer your concussion? _______/________/_______

(2) When you suffered this concussion, do you experience any of the following?

2. (a) Loss of Consciousness Yes No

(b) Amnesia (Memory Loss) Yes No

(3) Have you ever suffered a concussion before? Yes No

If Yes, how many? _____________

If Yes, when was the most recent concussion before this one?

____

(4) Have you ever been knocked out while playing your sport? Yes No

If Yes, how many times has this happened? _________

(5) Have you ever had your "bell rung" or "dinged" following a hit? to the head while playing your sport? Yes No

If Yes, has it happened this season? Yes No

If Yes how many times this season? ____________________

(6) Have you ever sprained your ankle? Yes No

If Yes, how many times? Left__________ Right____________

If Yes how many times this season? _________________________

How much time did you lose with your worst ankle sprain?

____

(7) Have you ever broken a bone in your leg? Yes No

If Yes, which bone? ___________________________

Does this injury still bother you? Yes No

(8) Have you ever hurt your knee? Yes No

If Yes, did you tear meniscus? Yes No

If Yes, did you have surgery? When?______________________

If Yes, did you ever tear a ligament? Yes No

If Yes did you have surgery, when, surgery?____

(9) Have you ever hurt your hip? Yes No

If Yes, please explain _____________________________________

(10) Have you ever strained or torn a leg muscle? Yes No

If Yes, please explain_____________________________________

(11) Have you injured your low back or had a nerve problem? Yes No

If yes, please explain: _____________________________________

(12) Do you have any known balance/metabolic/neurological disorders? Yes No

If Yes, please explain:_____________________________________

(13) Have you had any other muscle/bone/joint injuries to your head, back, leg, or feet? Yes No

If Yes, please explain: ________________________________
____
____

APPENDIX E

GEORGIA SOUTHERN UNIVERSITY CONCUSSION MANAGEMENT GUIDELINES

Georgia Southern University has established protocols to care for participants who have sustained a concussion which includes sideline assessment, symptom monitoring, balance and postural stability assessment, and neurocognitive assessment.

Policy 1.0: Preseason: Student-athletes

All Student-athletes will undergo the basic education regarding the signs and symptoms of concussions, what to look for and how to report them to the appropriate medical personnel. All student-athletes will then be required to sign an agreement indicating they will report any and all signs and/or symptoms of concussion to the appropriate medical personnel. This agreement also includes basic educational materials in reference of concussions. Each student-athlete will sign, date and have a signed witness to this agreement. After the proper signatures have been obtained the student-athlete will receive a carbon copy of the form in order to keep for their personal records.

GSU Athletic Training Department will administer a preseason neuropsychological test called ImPact. ImPact is a computer based, validated tool developed to help sports medicine clinicians evaluate cognitive recovery following concussion. ImPact will evaluate the following neuropsychological functions: word discrimination (memory), design memory (visual recognition), visual processing speed, symbol matching (visual processing speed, learning and memory), color match (reaction time and impulse control/response inhibition), and three letters (measures working memory and visual-motor response speed).

Each student-athlete will undergo a baseline testing of ImPact, SAC, BESS during pre-participation physicals.

During the education portion of this meeting the following will be discussed:

1. Concussion Signs and Symptoms
2. NCAA Executive Committee recommendations for concussion management
3. GSU's Concussion Management guidelines and protocols that incorporate the NCAA's most recent recommendations.
4. We will take any questions that student-athletes may have

Policy 1.1: Preseason – Coaches

All coaches employed by Georgia Southern University Athletics Department will be required to undergo a basic educational in-service with the appropriate Athletic Training medical personnel. During this in-service the following information will be discussed:

1. Concussion Signs and Symptoms
2. NCAA Executive Committee recommendations for concussion management

3. GSU's Concussion Management guidelines and protocols that incorporate the NCAA's most recent recommendations.

4. Explanation of the neurocognitive testing that is conducted as a baseline and as an evaluation post-concussion diagnosis

5. We will take any questions that coaches may have

<u>Policy 2.0: Diagnosis of Concussion</u>

For the purpose of this protocol, sports concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Several common features 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.

3. Concussion may result in neuropathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury.

4. Concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course.

5. Concussion is typically associated with grossly normal structural neuroimaging studies.

A concussion will be diagnosed by the Georgia Southern University Athletic Training Department that includes team physicians and healthcare providers that are experienced in the evaluation and management of concussions when a student-athlete reports one or more of the following signs and/or symptoms following a suspected direct or indirect blow to the head:

1. Cognitive Features:
    - Unaware of period, opposition, score of game (Maddock's questions)
    - Confusion
    - Amnesia
    - Loss of consciousness
    - Unaware of time, date, place
2. Typical Symptoms:
    - Headache
    - Dizziness
    - Nausea
    - Unsteadiness/loss of balance
    - Feeling "dinged," stunned or dazed, "foggy"
    - "having my bell rung"
    - Seeing stars or flashing lights
    - Double vision

Policy 2.0: Diagnosis of Concussion (continued)

3. Subjective Symptoms:

- Sleepiness
- Sleep disturbances
- Slowness/fatigue

4. Physical Signs:

- Loss of consciousness/impaired conscious state
- Poor coordination or balance
- Concussive convulsion/impact seizure
- Gait unsteadiness/loss of balance
- Slow to answer questions or follow directions
- Easily distracted, poor concentration
- Displaying inappropriate emotions (laughing, crying)
- Nausea/vomiting
- Vacant stare/glassy eyed
- Slurred Speech
- Personality Changes
- Inappropriate playing behavior (running in the wrong direction)
- Significantly decreased playing ability

Policy 2.1 Diagnosis of Concussion

Any student-athlete showing signs and/or symptoms of a concussion will be removed from all physical activities/competition for evaluation for the remainder of the day. Signs and symptoms of concussion have the tendency to clear quickly but the student-athlete may experience delayed symptoms or depressed neurocognitive levels.

Activities indicated include **ANY** activities on/off the field. The student-athlete will be evaluated through a series of tests that may or may not be limited to the following: thorough history to determine signs/symptoms, ImPact Post Injury Testing, SAC, GSC, BESS and possible exertion activities. Once the athlete has been diagnosed with a concussion by an athletics healthcare provider with experience in the evaluation and management of concussions, the student- athlete will be removed from participation for the remainder of the day. Neurocognitive/neuropsychological testing must follow the steps below:

- ImPact, SAC, GSC, BESS must be administered within 24-48 hours
- SAC, GSC, BESS must be administered daily until they meet B-Line
- ImPact is NOT to be administered again until the student-athlete is asymptomatic
- Once the student-athlete is asymptomatic, ImPact can be administered daily until B-Line has been met
- If student-athlete has passed and all tests reach B-Line, and they remain asymptomatic the step a day protocol can begin.

Policy 3.0: Referral

Any student-athlete diagnosed with a concussion will **NOT** return to play in the same day, and must pass a series of tests in order to return to play. The student-athlete must follow up with the team physician and follow the appropriate concussion management return to play protocols. The student-athlete will follow up with the team physician after they have completed the step/day protocol for ‘full go’ clearance.

The student-athlete will be referred to the emergency room or 911 will be activated if the following occur:

1. Inability to waken patient/unconsciousness-if they have regained consciousness R/O cervical spine injury and continue with transportation to the ER.
2. Severe or worsening headache
3. Disorientation or confusion that increases with time
4. Drowsiness that increases with time
5. Restlessness, unsteadiness that lasts longer than 15 minutes
6. Seizures
7. Difficulties with vision that lasts longer than 15 minutes
8. Vomiting, fever, or stiff neck
9. Urinary, bowel incontinence
10. Amnesia lasting longer than 15 minutes

Policy 4.0: Return to Play

Once a concussion has been determined a step/day protocol will be followed based on the length of the student-athlete’s signs/symptoms. The student-athlete will be permitted to move to the next step if they remain asymptomatic. The following protocol will be implemented once a concussion has been determined as the appropriate diagnosis:

Concussion with S/S lasting < 30 minutes:

Diagnosis day: OUT, rest for 24 hours, must be asymptomatic, All tests must be administered within 24-48hours of the injury and return to baseline scores

Day 1-Post Injury: Bike 10-15 minutes

Day 2-Post Injury: Elliptical 15-20 minutes and light weight lifting 20 minutes

Day 3-Post Injury: StairMaster 15 minutes and Exertional drills in controlled environment

Day 4-Post Injury: Non-contact practice 50-75%, weight lifting (non-contact)

Day 5-Post Injury: Non-contact practice 80-90%, weight lifting/plyometrics

Day 6-Post Injury: Contact Practice 100% – Full Go CANNOT BE GAME DAY!!!

Day 7-Post Injury: Released for Full Go activities

Concussion with S/S lasting > 30 minutes:

Diagnosis Day: OUT, rest 48 hours. All tests must be administered within 24-48 hrs of the injury and return to baseline scores.

Day 1-(Asymptomatic): Bike 10-15 minutes

Day 2-(Asymptomatic): Elliptical 15-20 minutes and light weight lifting 20 minutes

Day 3-(Asymptomatic): StairMaster 15 minutes & Exertional drills in controlled environment

Day 4-(Asymptomatic): Non-Contact Practice 50-75%, weight lifting full go (non-contact)

Day 5- (Asymptomatic): Non-Contact Practice 80-90%, weight lifting/plyometrics

Day 6- (Asymptomatic): Contact Practice 100% - Full GO-CANNOT BE GAME DAY!!!!

Day 7- (Asymptomatic): Released for Full GO activities

Policy 4.1: Return to Play

Once a concussion has been determined and the step/day protocol has begin

1. The team physician must be seen and clear the student-athlete to begin the protocol.

2. All tests must return to baseline readings.

3. The student-athlete must remain asymptomatic to advance to the next step in the protocol.

4. If the student-athlete advances to a step and begins experiencing signs/symptoms, they must discontinue ALL activities for the remainder of the day and they must regress back to the previous step the next day. **See Policy 4.2**

5. If the student-athlete remains asymptomatic throughout the protocol and able to advance step/day without complications, they must see a team physician prior to be released for 'full go' status.

Policy 4.2: Return to Play

Once a concussion has been determined and the step/day protocol has begun:

SYMPTOMS RETURN AFTER PROTOCOL HAS BEGUN:

1. The team physician must be seen and clear the student-athlete to begin the protocol.

2. All tests must return to baseline readings. **If tests have not returned to baseline see Policy 4.3.**

3. The student-athlete must remain asymptomatic to advance to the next step in the protocol.

4. If the student-athlete advances to a step and begins experiencing signs/symptoms, they must discontinue ALL activities for the remainder of the day and they must regress back to the previous step the next day.

5. If the student-athlete reports the following day still complaining of S/S, the protocol is discontinued and the student-athlete must REST until they are asymptomatic.

6. Once the student-athlete has returned asymptomatic, the athlete must be administered ImPACT, BESS, SAC and GSC again.

7. The athlete may only restart the protocol if all tests return to baseline **AND** the athlete has been seen and cleared to restart the step/day protocol by the team physician. **If tests have not returned to baseline see Policy 4.3.**

<u>Policy 4.3: Return to Play</u>

Once a concussion has been determined and the step/day protocol has begun:

SYMPTOMS DO NOT RETURN BUT IMPACT IS NOT BACK TO BASELINE, ALL OTHER TESTS ARE @ BASELINE:

1. The team physician must be seen and clear the student-athlete to begin the protocol.

2. All tests return to baseline readings but ImPact.

3. The student-athlete must remain asymptomatic to advance to the next step in the protocol.

4. If the student-athlete advances to a step and begins experiencing S/S , they must discontinue ALL

Activities for the remainder of the day and they must regress back to the previous step the next day.

5. If the student-athlete reports the following day still complaining of S/S, the protocol is discontinued and the student-athlete must REST until they are asymptomatic.

6. Once the student-athlete has returned asymptomatic, the protocol will start over from the rest period.

7. If the student-athlete is asymptomatic, all tests have returned to baseline but ImPact they must remain at cardio, exertional drills in controlled environment until ImPact has returned to baseline test scores.

8. ImPact will be taken daily until it reaches baseline testing score at this time.

Policy 5.0: 2nd Concussion of the season:

If a student-athlete with a documented concussion for the season is diagnosed with a second concussion in the same season or within 3 months of the previous concussion, the student-athlete should be removed for twice the maximum amount of time (Rest 1 week, can begin step/day protocol 2nd week as long as asymptomatic).

Policy 6.0: 3rd Concussion of the season:

If a student-athlete with 2 documented concussions for the season is diagnosed with a third concussion in the same season, the student-athlete will be disqualified from competition for the remainder of that respective season.

APPENDIX F

QUICKBOARD FIGURE

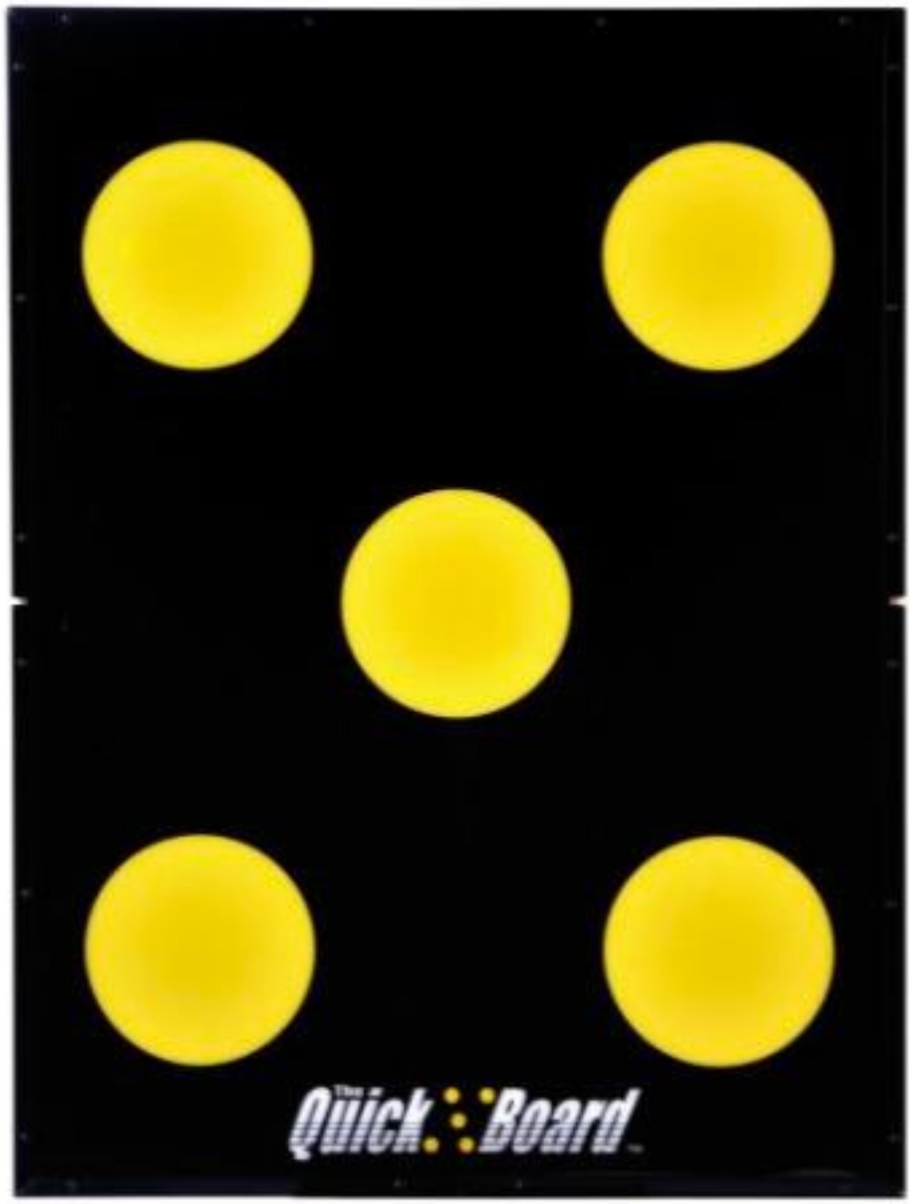

Figure 1. Quickboard matt

Figure 2. Quickboard tablet