EFFECTS OF A HISTORY OF CONCUSSIONS ON COGNITIVE FUNCTION IN COLLEGIATE WRESTLERS

A Thesis
by
MEREDITH LYNN BUSKARD

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APPROVED BY:

Scott Collier, Ph.D.
Chairperson, Thesis Committee

Alan Utter, Ph.D.
Member, Thesis Committee

Alan Needle, Ph.D.
Member, Thesis Committee

Travis Triplett, Ph.D.
Chairperson, Department of Health and Exercise Science

Max C. Poole, Ph.D.
Dean, Cratis D. Williams School of Graduate Studies

Abstract

EFFECTS OF A HISTORY OF CONCUSSIONS HAS ON COGNITIVE FUNCTIONS IN COLLEGIATE WRESTLERS

Meredith Buskard LAT ATC
B.A., Lynchburg College
M.A., Appalachian State University

Chairperson: Scott Collier, Ph.D.

A history of concussions prolongs cognitive recovery and has shown to affect neurocognitive degeneration, but it has not been investigated whether or not these aspects affect baseline cognitive scores. Therefore, the purpose of this study was to investigate the effects a history of concussions has on long-term neurocognitive function in collegiate wrestlers. Athletes ($n = 28$) were administered a neurocognitive computer test at the beginning of the wrestling season. We collected baseline concussion cognitive scores using Immediate Post-Concussion Assessment and Cognitive Test (ImPACT), concussion history, and post injury scores from collegiate wrestlers. All information was obtained prior to wrestling season, and post injury scores were recorded throughout the season. The results show athletes ($n = 2$) with a history of three or more concussions had decreased baseline verbal memory and visual memory baseline scores. Athletes that sustained concussions during the season had similar increases in reaction time, visual processing speed, and increased verbal and visual memory scores. Our results suggest that a history of three or more concussions had deleterious effects on neurocognitive function and could be shown using Immediate Post Concussion Assessment Test (ImPACT). Due to the small sample size, an exploratory data analysis (EDA) with notched boxplots was performed. Notched boxplots depicted variability among the verbal memory composite, visual memory composite, visual motor speed, reaction time, and impulse control baseline scores. The non-gaussian distributions suggest using non-parametric statistics for analysis. Using Spearmans Rho (-1 to +1), we found almost no relationship ($rs = -.07$) between verbal and visual memory composite scores. A moderate positive relationship ($rs = .38$) between visual memory control and visual motor speed and a weak positive relationship ($rs = .12$) between verbal memory composite and visual motor speed. Reaction time and visual memory control had a moderate negative relationship ($rs = -.42$). We conclude that a history of concussions may have effects on cognitive function, and using non-parametric statistics should be considered for future research in analyzing concussion score due to the non-gaussian distributions.

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Chapter 1

Introduction

A concussion is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces (McCrory et al., 2013). Concussions are becoming increasingly prevalent in athletics, with an estimated 1.6 to 3.8 million concussions occurring annually (Covassin, Moran, & Wilhelm, 2013). Symptoms associated with concussions are cognitive impairments such as slowed reaction times, headaches, dizziness, irritability, and memory impairment (McCrory et al., 2013). The deleterious effects of a concussion may or may not be detected at the time of injury. Based on the severity of a concussion, an athlete may have long term neurocognitive impairments and prolonged symptoms (Covassin et al., 2013). Individuals who have suffered more than one concussion are at an increased risk for more concussions, slower recovery, cognitive dysfunction, and postural instability (Guskiewicz et al., 2003). Adding to the complexity of diagnoses, concussions have no universal grading system because no two concussions are the same (Guskiewicz et al., 2004). Further, each individual reacts to concussions differently depending on the mechanism of injury and what signs and symptoms appeared following the concussive force.

Studies have investigated concussions in collision sports such as football, ice hockey, and soccer (Casson, Viano, Powell, & Pellman, 2011; Colvin et al., 2009; Kathryn, 2010);

however, few studies have investigated the long-term effects of a history of concussions in wrestling. There are aspects of wrestling that may increase the incidence of concussions, including player to surface contact, player to player contact, and takedowns (Marar, McIlvain, Fields, & Comstock, 2012). Player to surface contact accounts for 53.2% of concussions; 44.1% are attributed to player to player contact; and takedowns are attributable to 58.7% of concussions in this sport (Marar et al., 2012). Takedowns are practiced the most due to the scoring system used for wrestling, as they yield the most points; however, takedowns account for the most injuries in wrestling (Weber et al., 2013).

Several diagnostic tools have been created to diagnose concussions, allowing health care professionals to use a multifaceted approach to monitor symptoms and measure deficits in cognitive differences (Guskiewicz et al., 2004). There are several types of neurocognitive tests that evaluate an athlete's cognitive impairments pre- and post-concussion. An example of these tests is the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), a computer based neurocognitive test. ImPACT observes differences in neurocognitive function such as attention span, working memory, non-verbal problem solving, and reaction time (ImPACT, 2013). ImPACT can be used to determine if there is a cognitive difference between a baseline test completed before the start of the season and post-injury scores completed after an injury occurs (Guskiewicz et al., 2004). It is important to compare baseline and post-injury scores to evaluate if an athlete still has neurocognitive deficits. Comparing baseline and post-injury scores can prevent an athlete from returning to play too soon when there could be neurocognitive deficits (Broglio, Macciocchi, & Ferrara, 2007). Research has shown that ImPACT is a valid measure of neurocognitive performance in the acute stages of a concussion, but concussion severity may influence the outcomes of the results (Iverson, Lovell, & Collins, 2005; Maerlender et al., 2010; Schatz & Sandel, 2013).

Statement of the Problem

Studies have shown that athletes with a history of concussions have impaired cognitive performance (Broglio et al., 2007; Covassin et al., 2013). There is a paucity of literature investigating how a history of concussions affects the cognitive scores of the ImPACT test in collegiate wrestlers. The purpose of this study was to investigate the effects a history of concussions has on long-term neurocognitive function.

Hypothesis

It was hypothesized that there will be a positive association between the history of concussions and neurocognitive impairments.

Significance of the Study

It is important to understand whether or not a history of concussions has a deleterious effect on neurocognitive impairments in athletes involved in sports where the athletes endure repetitive head impact and have suffered multiple concussions. Determining if there are long-term neurocognitive impairments could allow medical professionals further understanding as to why some athletes may not fully recover neurocognitive function after a concussion.

Definition of Terms

Concussion: a complex pathophysiological process affecting the brain, induced by biomechanical forces (McCrory et al., 2013).

ImPACT: Immediate Post-Concussion and Cognitive Testing: a computerized concussion evaluating symptom (ImPACT, 2013).

Chapter 2

Literature Review

Introduction

Concussions have become an important topic of research in athletics, due to the increase in the number of sports related concussions (Colvin et al., 2009; Covassin et al., 2013). Concussions are diagnosed by a multifaceted approach using on-field assessments (SCAT2) and computer concussion tests (ImPACT) (McCrory et al., 2013). The on-field assessment and computer battery test measure signs, symptoms, and cognitive deficits in an individual suspected of a concussion.

A history of multiple concussions can prolong neurocognitive recovery on a concussed athlete (Covassin et al., 2013). Research has shown that individuals with a history of concussions are at an increased risk for future concussion, prolonged recovery, and prolonged symptoms (Covassin, Stearne, & Elbin III, 2008; Guskiewicz et al., 2003). Athletes with a history of three or more concussions presented more symptoms and performed worse on neurocognitive tests compared to their baseline scores (Iverson, Gaetz, Lovell, & Collins, 2004). Studies by Iverson et al. (2004) and Covassin et al. (2013) reported that athletes with a history of concussions were impaired with verbal memory five to eight days after a subsequent concussion.; however, these studies investigated the effects a history of concussions has on the impairments after a recent concussion. Future studies should be conducted on whether or not a history of concussions could cause long-term neurocognitive deficits.

Research has investigated concussions in football and other collision sports, but there has been no research examining concussions in wrestling (Casson et al., 2011; Delaney, Lacroix, Leclerc, & Johnston, 2002). The purpose of this study was to investigate the effects a history of concussions has on neurocognitive function using a collegiate wrestling team and the ImPACT test.

Pathophysiology of Concussions

A concussion is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces (McCrory et al., 2013). Concussions can be caused by a direct blow to the head, face, neck, or elsewhere on the body that causes an impulsive force that is transmitted to the head (McCrory et al., 2013). When the brain receives an impulsive force, that force causes a disruption of ionic, metabolic, and pathophysiological balances in the brain (Harmon et al., 2013). In order to reestablish ionic balance, the brain needs energy to promote normal metabolism (Harmon et al., 2013). However, the brain's need for energy occurs at a time when the body has decreased cerebral blood flow and mitochondrial dysfunction (Harmon et al., 2013), so the brain cannot function properly. Once an athlete is diagnosed with a concussion, it is imperative the athlete receive mental and physical rest in order to re-establish ionic balance (Guskiewicz et al., 2004; Harmon et al., 2013).

Medical professionals evaluate and diagnose athletes suspected of a concussion based on signs and symptoms, including headache, dizziness, fatigue, difficulty concentrating, difficulty remembering, blurred vision, difficulty sleeping, and neurocognitive deficits (Casson et al., 2011; McCrory et al., 2013). Evidence suggests that a concussed brain is less responsive to neural activation when cognitive or physical activity occurs before the brain has time to heal (Harmon et al., 2013). In order to ensure the brain has healed, athletes need to have adequate rest and pass a "return to play" protocol.

Athletes who have a history of concussions have an increased risk of future concussions (Covassin et al., 2008). One study investigated the effects a concussion history has on cognitive functions and found that verbal memory and reaction time were impaired the longest (Covassin et al., 2008). Research also states that athletes with a history of three or more concussions presented with poorer performance on neurocognitive tests compared to those with no previous history of a concussion (Covassin et al., 2008). Future research should look at long-term neurocognitive impairments on athletes who have a history of concussions.

Concussions in Sport

An estimated 1.6 to 3.8 million sport related concussions occur annually (Langlois, Rutland-Brown, & Wald, 2006). Studies have investigated concussions involved in sports such as football, ice hockey, and soccer; but there have been few studies investigating concussions in wrestling (Casson et al., 2011; Colvin et al., 2009; Kathryn, 2010; Marar et al., 2012). One study used football players, cheerleaders, soccer players, and equestrian riders to investigate whether or not neurocognitive deficits existed after concussion symptoms subsided. The study found that there were still neurocognitive deficits in athletes whose concussion symptoms had subsided (Broglio et al., 2007). This research shows that neurocognitive deficits can still be found in athletes who no longer have symptoms of a concussion, but it did not examine whether a concussion history could have long term effects on neurocognitive deficits. A study that observed frequent head impact exposure in football players stated that the neurologic symptoms are influenced by location or direction of impact (Crisco et al., 2010). This study only looked at football players, but other sports such as wrestling receive frequent head impact exposures in moves such as takedowns. Takedowns account for majority of the injuries involved in wrestling due to the direct contact with the opponent's head, neck, elbow, and knee (Weber et al., 2013). Since there is a potential for repetitive contact of the head in practices as well as matches, it is important to consider that subconcussive blows could contribute to the deleterious effects on cognitive function.

Although there are different styles of wrestling (Greco Roman, freestyle, and folkstyle), all involve takedown maneuvers, player to player contact, and player to surface contact. Yard and Comstock (2008) found that there were 24.1% concussions sustained in Greco Roman wrestling compared to the 12.1% sustained in freestyle wrestling (Yard & Comstock, 2008). Collegiate wrestling uses folkstyle wrestling, which is similar to freestyle, but with an increased focus on controlling an opponent (Yard & Comstock, 2008). The increased control on an opponent could result in a decrease in incidences concussions, however there are minimal studies investigating the incidence of concussions in folkstyle wrestling.

ImPACT Concussion Testing

Medical professionals use different assessment tools to evaluate an athlete suspected of a concussion. On field assessment tools, such as the Sport Concussion Assessment Tool 2

(SCAT2) and Balance Error Scoring System (BESS), evaluate cognitive and postural functions. Paper based assessments have limitations, such as practice effects and extensive time requirements for scoring and interpretation (Schatz & Sandel, 2013). Computer based assessments decrease practice effects (P. Schatz & Ferris, 2013) and can detect subtle cognitive changes, which paper based assessments cannot do (Covassin, Elbin III, Stillier-Ostrowski, & Kontos, 2009). The Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) is a computer-based test used to evaluate cognitive functions such as reaction time and impulse control. The ImPACT has eight modules that test immediate design and delay recall, a symbol-match test, a three letter recall, the Xs and Os test, and a color test (Resch et al., 2013). The neurocognitive test modules combine to create four composite scores for verbal memory, visual memory, visual motor speed, and reaction time (Broglio et al., 2007).

Baseline testing is used to establish a normal score for each athlete and allows for a comparison post-concussion (Schmidt, Register-Mihalik, Mihalik, Kerr, & Guskiewicz, 2012). Covassin et al. (2008) found that athletes with a history of three or more concussions performed worse on neurocognitive tests after a subsequent concussion. Research has investigated a history of concussions and their effects on ImPACT after a subsequent concussion; however, a history of concussions should not be eliminated since it has effects on cognitive function.

Conclusion

Concussions have become a prevalent injury in sports such as football, ice hockey, lacrosse, soccer, and wrestling. Studies have evaluated concussions in different styles of wrestling, the effects of dehydration on wrestling, and the mechanisms of how a wrestler can sustain a concussion. However, there have been no studies evaluating the effects a history of concussions has on cognitive scores of collegiate wrestlers. Therefore, it is important to investigate the relationship between history of concussions and neurocognitive function in collegiate wrestlers.

Chapter 3

Methodology

Research has shown that athletes who have a history of concussions have a decreased neurocognitive performance after a recent concussion. Studies have investigated incidences of concussions in football and hockey, but there are no studies examining the effects of concussion history and subconcussive blows in wrestling. It is unknown if there are long-term effects from subconcussive blows and a history of concussions on neurocognitive function. Therefore, the purpose of this study was to investigate the relationship between a history of concussions and neurocognitive function on a collegiate wrestling team.

Subjects

This study used a Division I wrestling team, approximately 23 athletes, between the ages of 18 to 24 of all weight classes. All athletes on the team were included in this study regardless of previous history of concussions. Athletes were active members on the wrestling team, participated in daily practices and in matches or tournaments. The athletes were informed of the testing, research, and purpose of the study prior to signing a medical release form allowing access to their medical histories.

Research Design

The athletes were administered a 30-minute neurocognitive concussion assessment computer test (ImPACT) at the beginning of the season in October. Each athlete signed up for a time at which they could take the baseline ImPACT test. The ImPACT test was administered in an office, located in the athletic training facility; and each athlete was monitored by an athletic trainer during ImPACT testing. All athletes were instructed to turn their phones on silent and to lay the phone facedown to decrease the risk of being distracted. Since each athlete took the test alone and was closely monitored, there was no need to take away the cellular device. The athletic trainer monitored the athlete outside of the office so that the athlete was in a quiet environment with minimal distractions. ImPACT measures symptoms, verbal memory, visual memory, processing speed, and reaction time (ImPACT, 2013). Before completing the ImPACT test, athletes met with the researchers involved and completed a medical history questionnaire containing information on previous concussions and any medications being taken at the time of the ImPACT test. Throughout the season any athletes who sustained a concussion were documented but not excluded from the study. All wrestlers who sustained a concussion used ImPACT in their "return to play" protocol but were still included in the study. Each wrestler's post-injury score was collected in order to compare baseline scores.

The outcome measures included the athlete's previous concussion history and the five individual composite scores from the ImPACT test pre-season and post-season. A spreadsheet on a password-protected computer contained the data for the outcome measures throughout this study. Every athlete served as his own control because concussions and their effects vary from person to person.

ImPACT

Verbal Memory Composite Score

Verbal memory composite score consists of three ImPACT test modules: symbol matching, three letter memory, and total memory correct. Symbol matching evaluates visual processing speed, learning, and memory. Three letters memory assess working memory and visual-motor response speed, and the total memory percent correct is the total amount of the verbal memory correct out of all the modules. A higher score indicates a better verbal memory composite (ImPACT, 2013).

Visual Memory Composite Score

Visual memory composite score contains the two modules of design memory and Xs and Os. Design memory evaluates attentional processes and visual recognition memory by using a design discrimination model. The Xs and Os measures visual working memory and processing speed through a visual memory model paired with a distracter task that measures visual reaction time. A higher visual memory score indicates better performance (ImPACT, 2013).

Processing Speed Composite

Processing speed composite score consists of the total correct for the Xs and Os module and three letters test module. The Xs and Os as well as the three letters memory were described in the previous visual memory composite and verbal memory composite sections. A higher score indicates a better processing speed performance (ImPACT, 2013).

Reaction Time Composite

Reaction time composite is composed of Xs and Os, symbol match, and color match. The Xs and Os section is described in the visual memory composite section. Symbol match evaluates processing speed, learning, and memory. Color match is a choice reaction time task that also measures impulse control and response inhibition. A lower score indicates a better performance on reaction time composite (ImPACT, 2013).

Impulse Control Composite

The impulse control composite consists of Xs and Os and color match. Xs and Os were discussed in the visual memory composite section and color match was described in the reaction time composite section. A low score indicates a better a lower impulse control composite (ImPACT, 2013).

Data Collection

ImPACT Composite Scores

At the beginning of the wrestling season, the verbal memory composite, visual memory composite, processing speed, and impulse control scores from ImPACT computer neurocognitive assessment were collected and sorted into an Excel database on a password protected computer. The ImPACT test has a password protected online database where all the athletes scores are kept after each test is taken with ImPACT. The password was obtained with permission from the athletic trainer in order to record the athlete's composite scores. The names of the wrestlers were coded to protect their identities and to make sure that both the pre- and post-season ImPACT scores were correctly matched. Each wrestler's concussion history was obtained through the medical history documentation filled out prior to taking the ImPACT test. The wrestler's previous number of concussions and medications were documented in the same spreadsheet as the ImPACT composite scores. Due to the small sample size and non-gaussian distribution, we used non-parametric statistics to examine the data to frame our discussion.

Treatment of Data

A one-way ANOVA was used to determine the subject characteristics to compare the pre-post means.

Due to the small sample size, we performed an exploratory data analysis (EDA) with notched boxplots for all of the dependent variables. Notched Boxplots were used with all variables to help understand some of the shape characteristics of the dataset distribution. Additionally, a visual inspection of the notches acts as a non-parametric, significance test of the group medians. Notches that are visually distinct from one another indicate significant median differences and notches that overlap in any respect indicate non-significant median differences. Following a visual inspection, we determined that the visual and reaction time variables showed the greatest visually distinct mean scores.

Considered the following inequalities from Theorem 2.2.4 (Karian & Dudewicz, 2000): Data with $\alpha_4 < 1+ \alpha_3^2$ where α_4=kurtosis and α_3^2 =skewness^2 fall into the *Impossible Region* of (skewness^2, kurtosis) space – i.e., they cannot be fit via *ANY* statistical distribution, and data with $\alpha_4 > 1+ \alpha_3^2$ can be fit by at least one statistical distribution. For all visual and reaction time variables, the inequality $\alpha_4 > 1+ \alpha_3^2$ held; therefore, these data can be fit by at least one statistical distribution. We used the Method of Moments (MOM) fitting procedure to describe the data set in terms of statistical fitting.

For the MOM fitting procedure, the population moments, α_1, α_2, α_3, and α_4, were set equal to the dataset moments $\hat{a}_1$, $\hat{a}_2$, $\hat{a}_3$, and $\hat{a}_4$ and the resulting equations were solved for the GLD parameters λ_1, λ_2, λ_3, and λ_4. The expressions for $\hat{a}_1$, $\hat{a}_2$, $\hat{a}_3$, and $\hat{a}_4$ are

$$\alpha=\mu=E(X)=\lambda_1+\frac{A}{\lambda_2},$$

$$\alpha_2=\sigma^2=E\left[(X-\mu)^2\right]=\frac{B-A^2}{\lambda_2{}^2},$$

$$\alpha_3=\frac{E(X-E(X))^8}{\sigma^8}=\frac{C-3AB+2A^8}{\lambda_2{}^8\sigma^8}$$

$$\alpha_4=\frac{E(X-E(X))^4}{\sigma^4}=\frac{D-4AC+6A^2B-3A^4}{\lambda_2{}^4\sigma^4},$$

where

$$A=\frac{1}{1+\lambda_8}-\frac{1}{1+\lambda_4},$$

$$B=\frac{1}{1+2\lambda_8}+\frac{1}{1+2\lambda_4}-2\beta(1+\lambda_3,1+\lambda 4)$$

$$C=\frac{1}{1+3\lambda_8}-\frac{1}{1+3\lambda_4}-3\beta(1+2\lambda_3,1+\lambda_4)+3\beta(1+\lambda_3,1+2\lambda_4),$$

$$D=\frac{1}{1+4\lambda_8}+\frac{1}{1+4\lambda_4}-4\beta(1+3\lambda_3,1+\lambda 4)+6\beta(1+2\lambda_3,1+2\lambda_4)-4\beta(1+\lambda_3,1+3\lambda_4).$$

Chapter 4

Results

Characteristics of Participants

Baseline scores and concussion history were collected from 28 Division I wrestlers. Eleven subjects were identified with a history of concussion; two subjects had a history of four concussions; eight subjects had a history of one concussion; and one subject had a history of two concussions as seen in Table 1. The subjects were 19.60 (± 1.41) years of age, average height 176.78 (± 9.41) centimeters, and mean weight of 74.90 (± 13.0) kg.

ImPACT Scores Distribution

Figure 1 compares the descriptive statistics between memory verbal composite and memory visual composite. Memory composite verbal (-.691) and memory composite visual (-.558) are left skewed. As shown in Figure 2, visual motor speed (-.524) is clearly leftward while reaction time composite (.843) was skewed to the right (see Figure 3a) as was impulse control (see Figure 3b).

Linear relationships between ImPACT scores

Scatterplots were constructed to demonstrate the relationship between the different ImPACT scores. We used Spearmans Rho (range -1 to +1) to determine if there is a linear relationship between memory control verbal score and memory control visual. The results showed almost no relationship (rs = -.07, see Figure 4). Memory control visual score and visual motor speed scores had a moderate positive relationship with a value of rs = .38 (see Figure 5). As shown in Figure 6, memory control verbal score and visual motor speed had a weak positive relationship with a value of rs = .12. Reaction time and memory control visual (rs = -.42) scores had a moderate negative relationship (see Figure 7). Reaction time and memory composite verbal score (rs = .04) had a weak positive relationship, as shown in Figure 8.

Relationships of ImPACT scores and Non-gaussian data

Univariate data was analyzed with two different GLD fits for ImPACT scores using the Method of Moments. The Algorithm GLD-M represented by the curve ($\lambda_1 = 92.4857$, $\lambda_2 = 0.0175$, $\lambda_3 = 0.1604$, $\lambda_4 = 0.0417$) was a better fit for the memory control verbal scores versus visual memory composite scores (see Figure 9a and Figure 9b). Visual motor speed fit the Algorithm GLD-M curve created using these parameters $\lambda_1 = 41.8386$, $\lambda_2 = 0.0228$, $\lambda_3 = 0.2023$, $\lambda_4 = 0.0636$. As shown in Figure 10a, both curves fit the visual motor speed scores, however the Algorithm GLD-M curve ($\lambda_1 = 41.8386$, $\lambda_2 = 0.0228$, $\lambda_3 = 0.2023$, $\lambda_4 = 0.0636$) sets a different middle point of the curve. The curve ($\lambda_1 = 0.5151$, $\lambda_2 = 2.7365$, $\lambda_3 = 0.0031$, $\lambda_4 = 0.3254$) to fit the reaction time scores had areas of under-fitting and over-fitting, but the fit is adequate and appropriate (see Figure 10b). The same Algorithm GLD-M curve ($\lambda_1 = 0.5559$, $\lambda_2 = 0.0041$, $\lambda_3 = 0.0001$, $\lambda_4 = 0.0241$) fit the impulse control scores adequately and appropriately (see Figure 11).

History of Concussions	Number of Athletes
0	17
1	8
2	1
4	2

Table 1: Concussion history of athletes (n = 28): most athletes had no history of concussions prior to baseline testing. The concussion history was self-reported prior to attending college. The athletic trainer recorded any concussions that occurred during collegiate wrestling. Eight athletes had one previous history of a concussion, and two athletes had a history of four concussions.

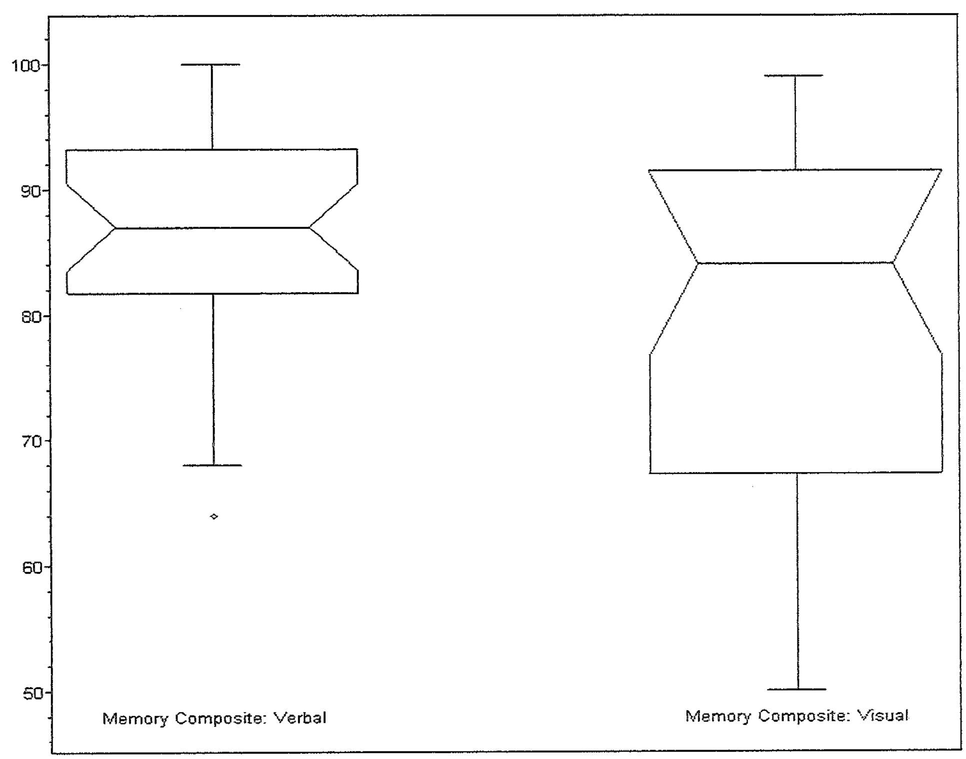


Figure 1: Box plots comparing Visual memory composite baseline scores (mean = 86.9, skewness = -0.69, kurtosis = 3.52) and Verbal memory composite baseline scores (mean = 79.5, skewness = -0.56, kurtosis = 1.99) of all subjects (n = 28).

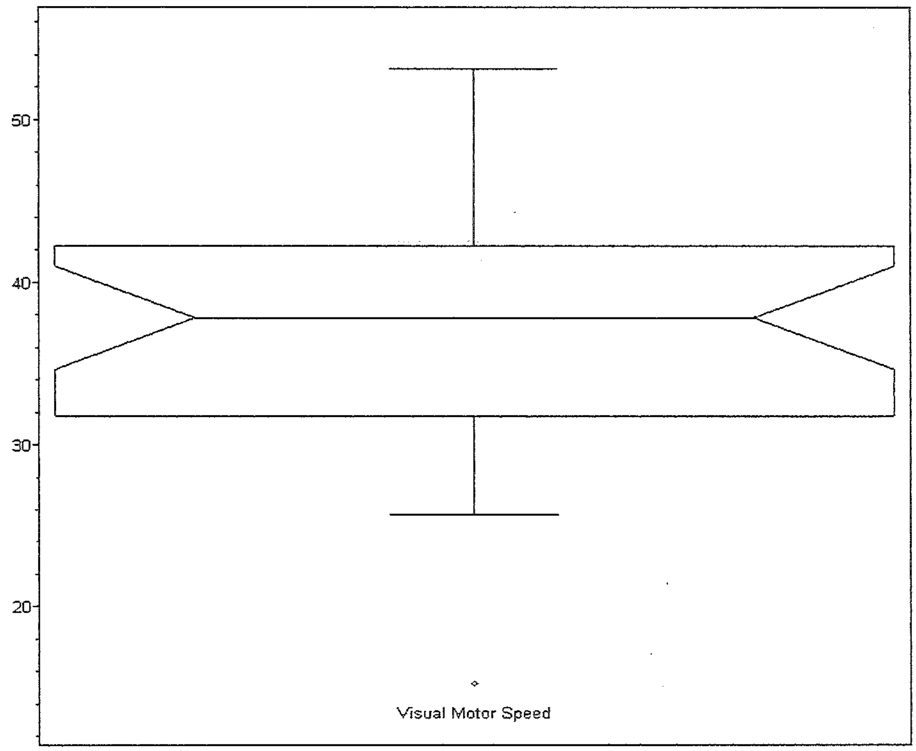


Figure 2: Visual motor speed baseline scores (mean = 37.1, skewness = -0.52, kurtosis = 3.15) of all athletes (n = 28).

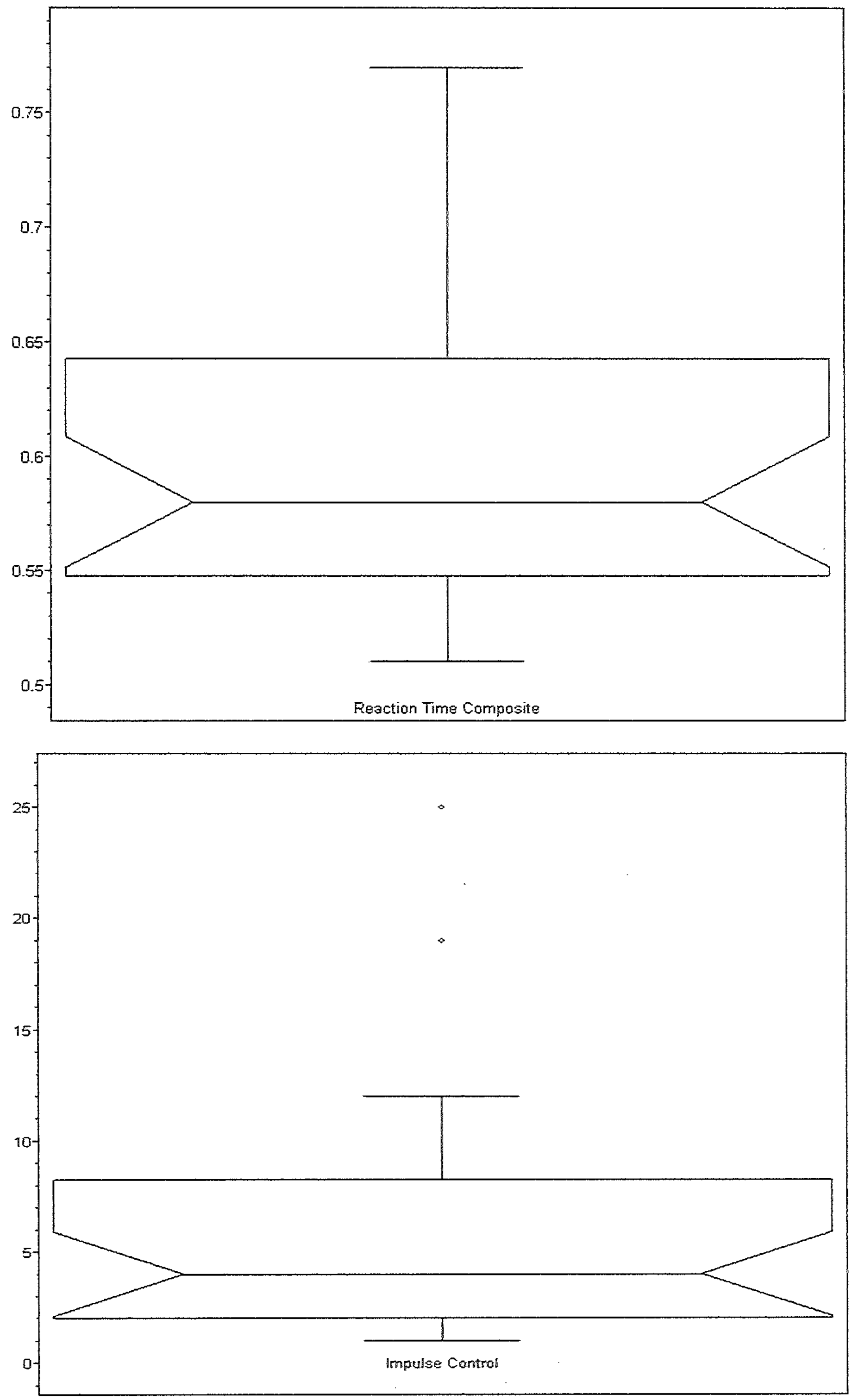


Figure 3: Reaction time composite baseline scores (3a) (n = 28, mean = 0.6, skewness = 0.84, kurtosis = 2.62) and Impulse control baseline scores (3b) distribution of athletes (n = 28, mean = 6.15, skewness = 1.86, kurtosis = 6.41).

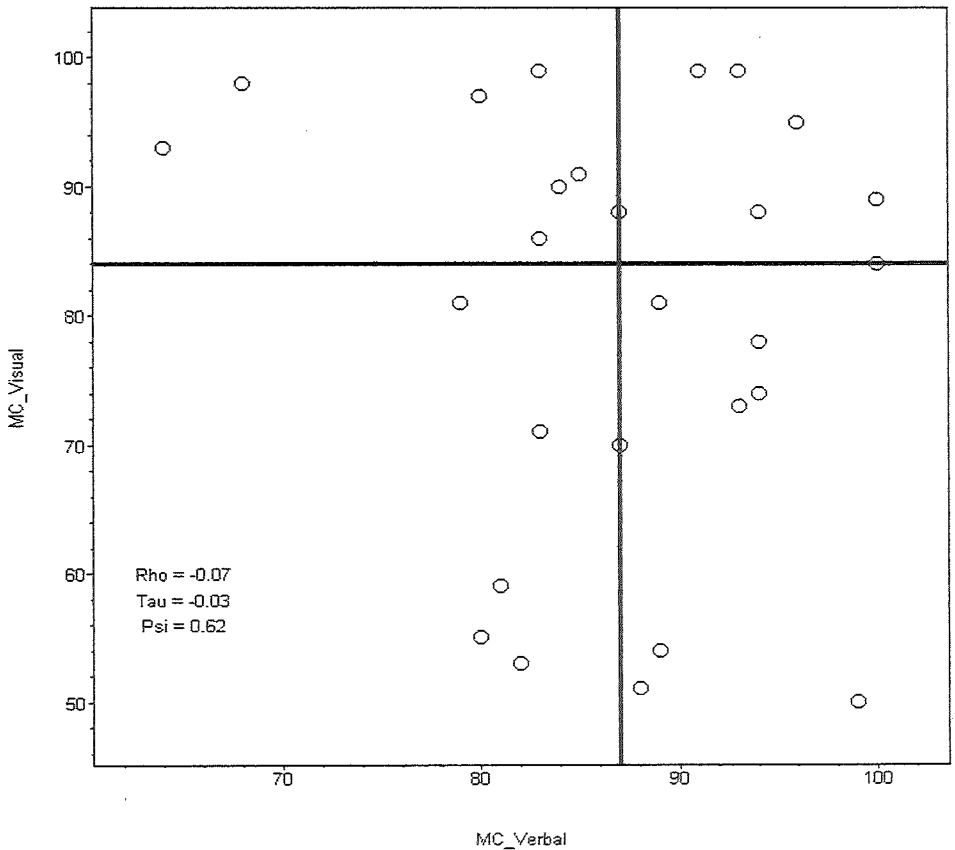


Figure 4: Scatterplot showing Spearmans Rho correlation between Verbal and Visual Memory Composite (n = 28). These data served as sample estimates of the marginal distributions X and Y for the GLD-2 approximation. Using Plackett's (1965) Method of bivariate distribution function construction (and Mardia's (1967) finding that the median makes for a less variable constant), the GLD-2 fit was obtained from the following steps: added the lines x = median of X and y = median of Y to produce the four quadrants a, b, c, and d; counted the number of data points in each of the four quadrants; and calculated Plackett's Psi (Ψ^{+}) where $\Psi^{+} = (a \bullet d)/(b \bullet c)$.

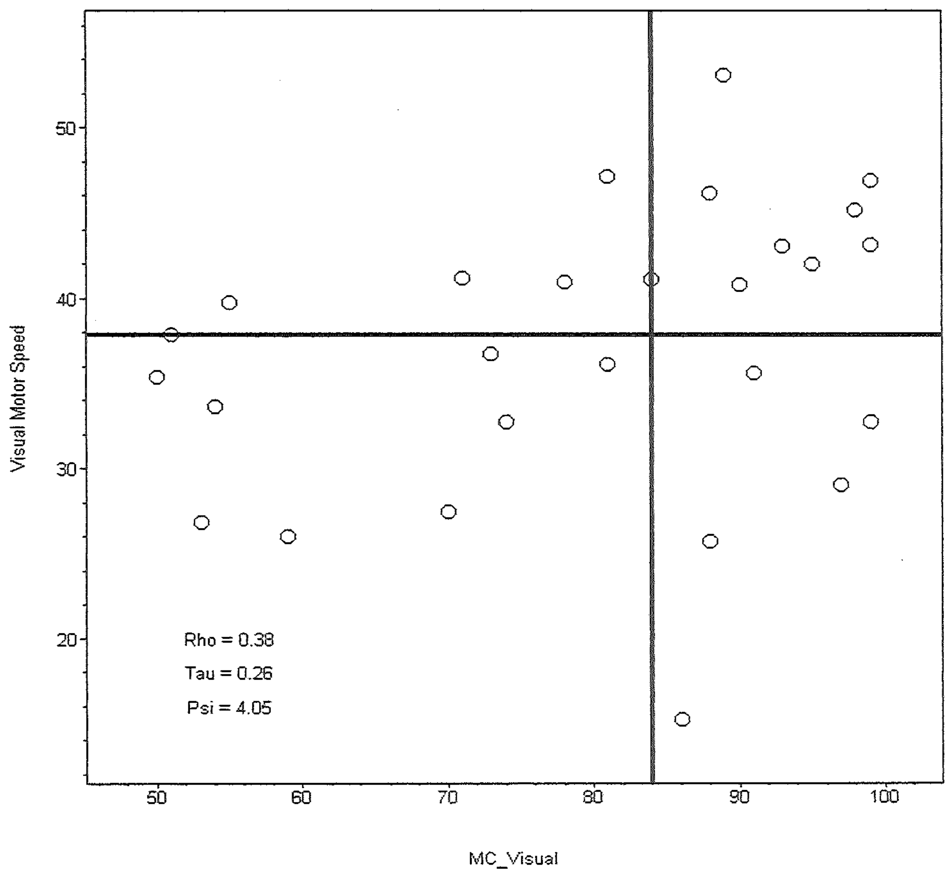


Figure 5: Scatterplot showing Spearmans Rho correlation between Visual Motor Speed and Visual Memory Composite (n = 28). These data served as sample estimates of the marginal distributions X and Y for the GLD-2 approximation. Using Plackett's (1965) Method of bivariate distribution function construction (and Mardia's [1967] finding that the median makes for a less variable constant), the GLD-2 fit was obtained from the following steps: added the lines x = median of X and y = median of Y to produce the four quadrants a, b, c, and d; counted the number of data points in each of the four quadrants; and calculated Plackett's Psi (Ψ^+) where $\Psi^+ = (a \bullet d)/(b \bullet c)$.

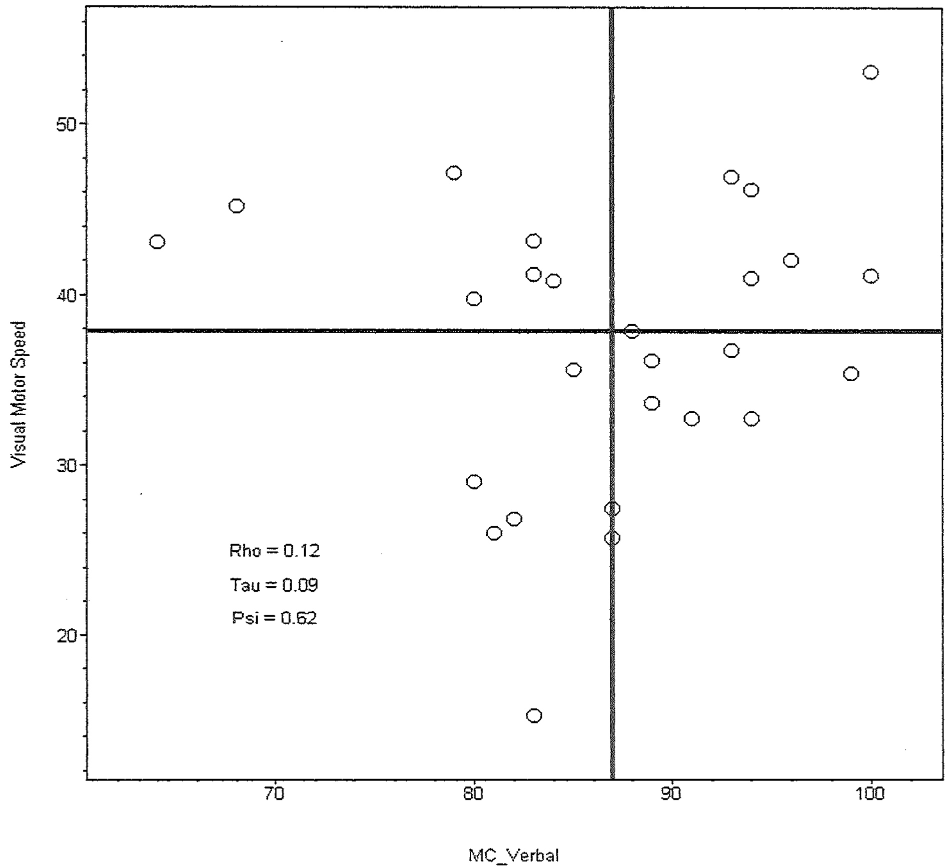


Figure 6: Scatterplot showing Spearmans Rho correlation between Visual Motor Speed and Verbal Memory Composite (n = 28). These data served as sample estimates of the marginal distributions X and Y for the GLD-2 approximation. Using Plackett's (1965) Method of bivariate distribution function construction (and Mardia's [1967] finding that the median makes for a less variable constant), the GLD-2 fit was obtained from the following steps: added the lines x = median of X and y = median of Y to produce the four quadrants a, b, c, and d; counted the number of data points in each of the four quadrants; and calculated Plackett's Psi (Ψ^{+}) where $\Psi^{+} = (a \cdot d)/(b \cdot c)$.

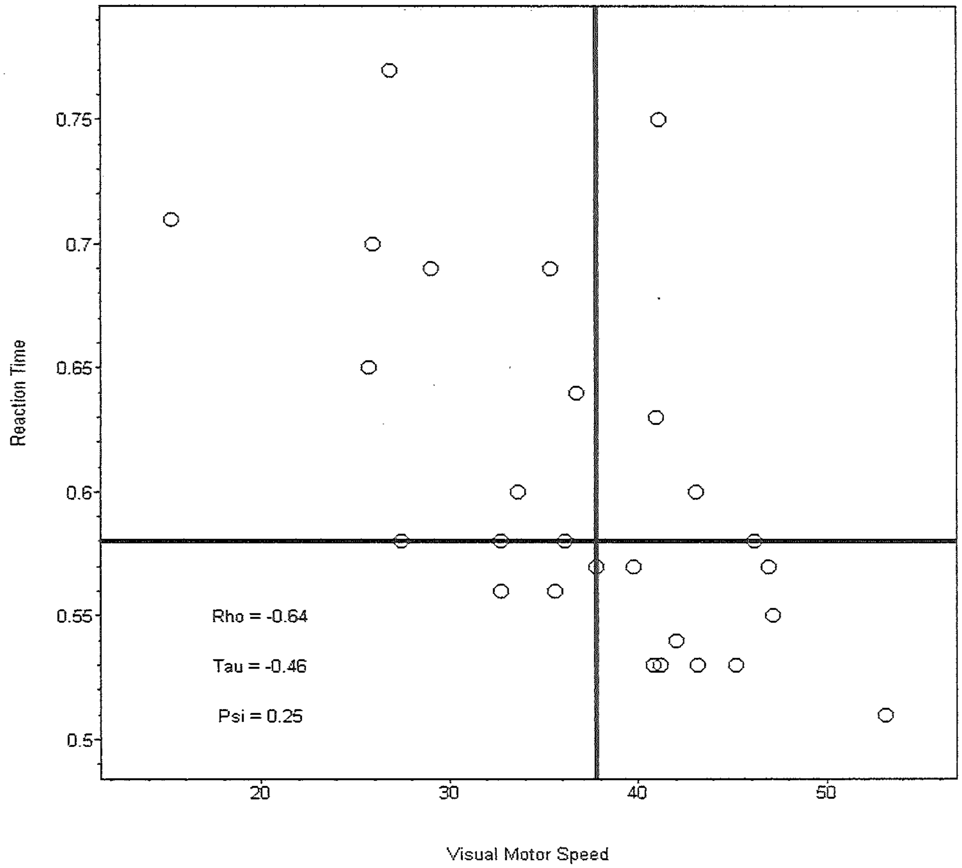


Figure 7: Scatterplot showing Spearmans Rho correlation between Reaction Time and Visual Motor Speed (n = 28). These data served as sample estimates of the marginal distributions X and Y for the GLD-2 approximation. Using Plackett's (1965) Method of bivariate distribution function construction (and Mardia's [1967] finding that the median makes for a less variable constant), the GLD-2 fit was obtained from the following steps: added the lines x = median of X and y = median of Y to produce the four quadrants a, b, c, and d; counted the number of data points in each of the four quadrants; and calculated Plackett's Psi (Ψ^+) where $\Psi^+ = (a \bullet d)/(b \bullet c)$.

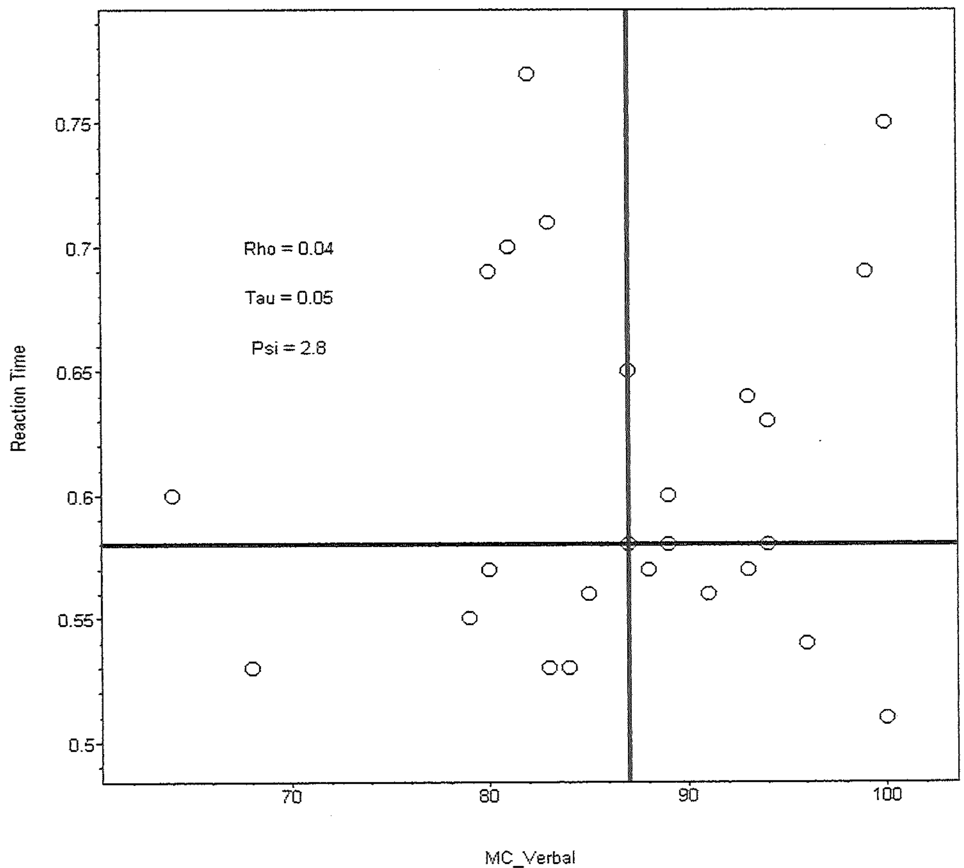


Figure 8: Scatterplot showing Spearmans Rho correlation between Reaction Time and Verbal Memory Control (n = 28). These data served as sample estimates of the marginal distributions X and Y for the GLD-2 approximation. Using Plackett's (1965) Method of bivariate distribution function construction (and Mardia's [1967] finding that the median makes for a less variable constant), the GLD-2 fit was obtained from the following steps: added the lines x = median of X and y = median of Y to produce the four quadrants a, b, c, and d; counted the number of data points in each of the four quadrants; and calculated Plackett's Psi (Ψ^+) where $\Psi^+ = (a \bullet d)/(b \bullet c)$.

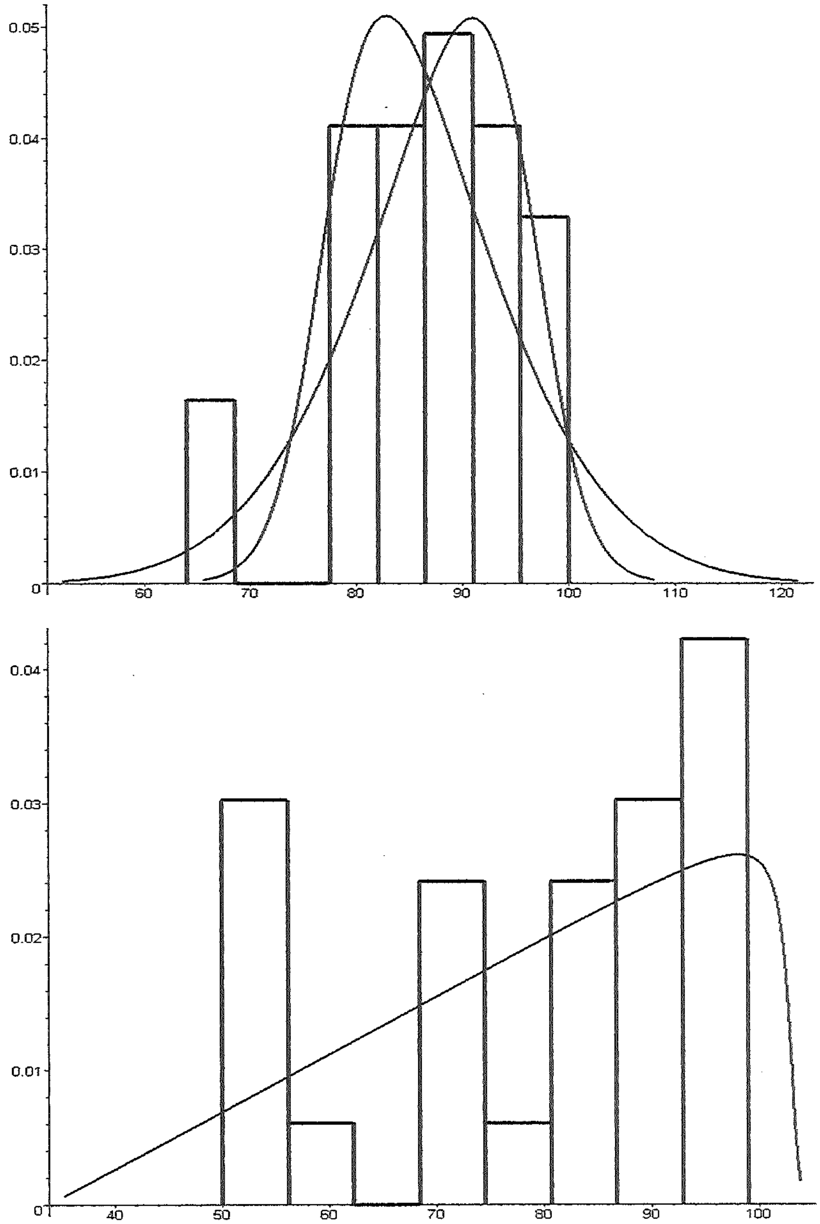


Figure 9: Method of moments for Verbal Memory Composite baseline scores (9a) (n = 28) versus Visual Memory Composite baseline (9b) scores (n = 28).

GLD_{MOM} table fit (λ_1= 110.9066, λ_2= 0.0050, λ_3= 0.1948, λ_4= 0.1153)

GLD_{MOM} program fit (λ_1= 87.9466, λ_2= 0.0052, λ_3= 0.1231, λ_4= 0.2020)

Notes on G-O-F. There are both overall similarities and subtle differences in these two MOM fits. The overall shape of the two distributions is similar; and yet, the location parameter is different in each case. Also, the GLD_{MOM} table fit has a longer and heavier *left tail* and GLD_{MOM} program fit has a longer and heavier *right tail*. These longer and heavier tails indicate a greater number of x values in this region and a greater proportion of the overall probability assigned to these values.

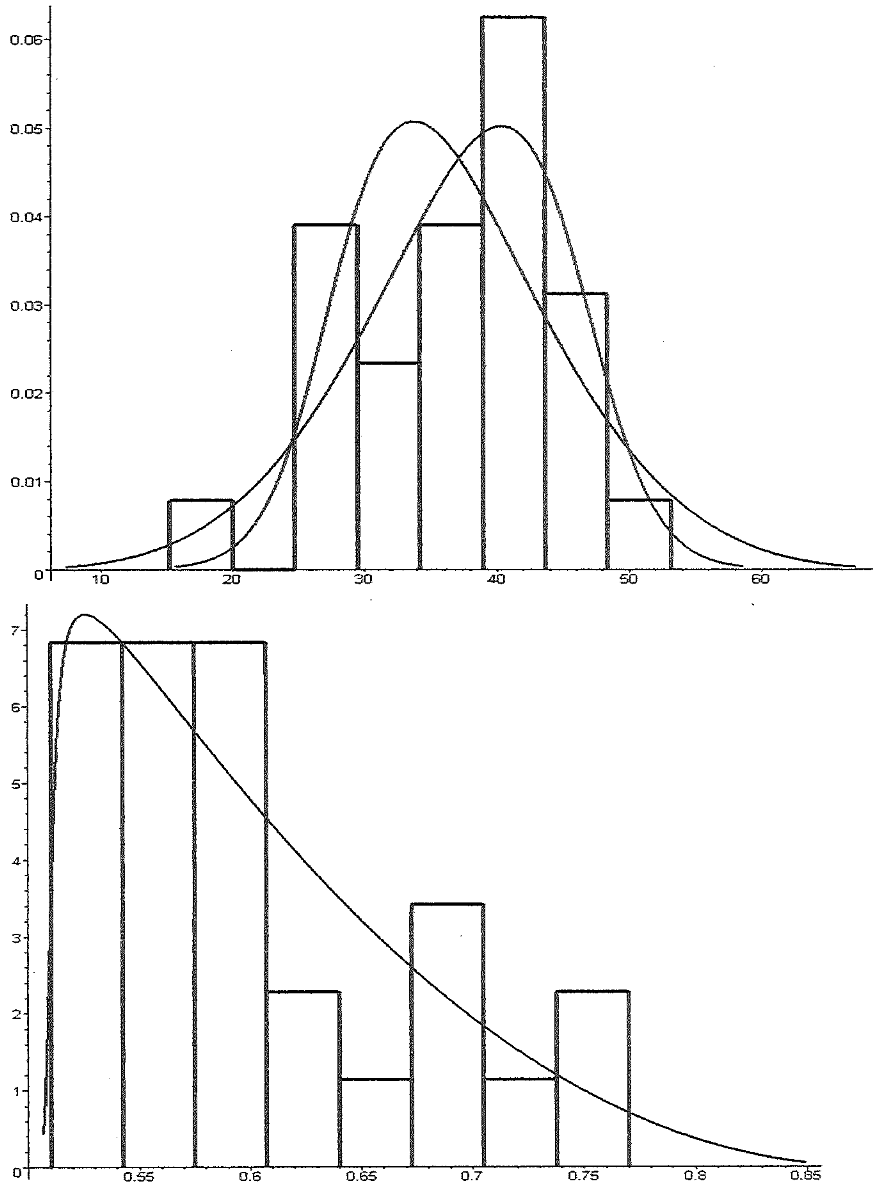


Figure 10: Method of moments Visual Motor Speed baseline scores (10a) and Method of moments Reaction Time baseline scores (10b).

Figure 10a:

GLD_{MOM} table fit (λ_1= 41.8386, λ_2= 0.0228, λ_3= 0.2023, λ_4= 0.0636)

GLD_{MOM} program fit (λ_1= 32.2999, λ_2= 0.0222, λ_3= 0.0605, λ_4= 0.1957)

Notes on G-O-F. There are both overall similarities and subtle differences in these two MOM fits. The overall shape of the two distributions is similar; and yet, the location parameter is different in each case. Also, the GLD_{MOM} table fit has a longer and heavier *left tail* and GLD_{MOM} program fit has a longer and heavier *right tail*. These longer and heavier tails indicate a greater number of x values in this region and a greater proportion of the overall probability assigned to these values.

Figure 10b:

Histogram of the data for Reaction Time along with one GLD fit obtained via the Method of Moments (M.O.M.) using the table-based, Algorithm GLD-M shown in blue -==---. Notice the areas of under-fitting and over-fitting, but also notice that the fit is both adequate and appropriate in terms of the *spread of data* vs. *distribution support.*

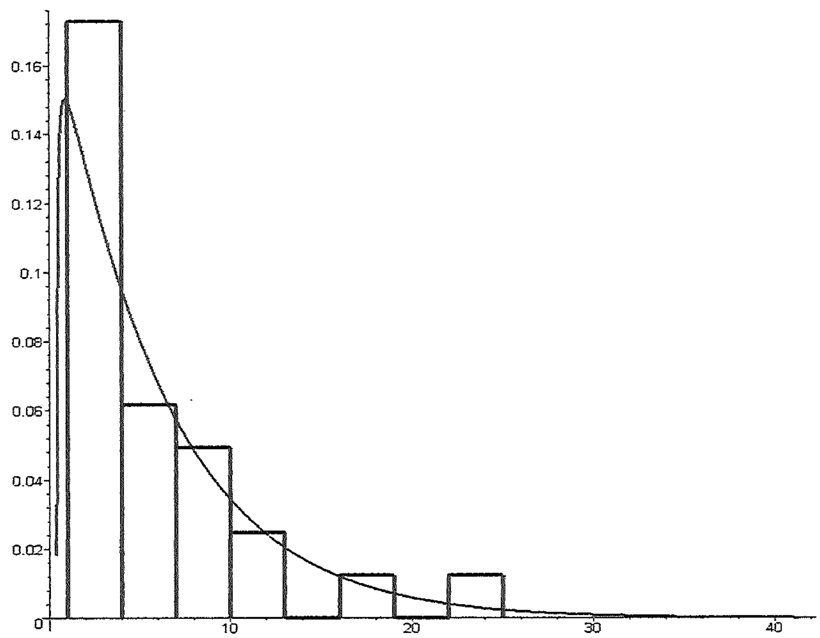


Figure 11: Method of moment for Impulse Control baseline scores (n = 28).

GLD_{MOM} table fit (λ_1= 0.5559, λ_2= 0.0041, λ_3= 0.0001, λ_4= 0.0241)

Histogram of the data for Impulse Control along with one GLD fit obtained via the Method of Moments (M.O.M.) using the table-based, Algorithm GLD-M shown in blue. Notice the areas of under-fitting and over-fitting, but also notice that the fit is both adequate and appropriate in terms of the *spread of data* vs. *distribution support.* The spread of data is the minimum and maximum values in the dataset and the distribution support comprises the minimum and maximum values of a particular theoretical distribution. And so, support is adequate if and only if the support covers the data spread; and support is appropriate if and only if reasonable values are included and unreasonable values are excluded.

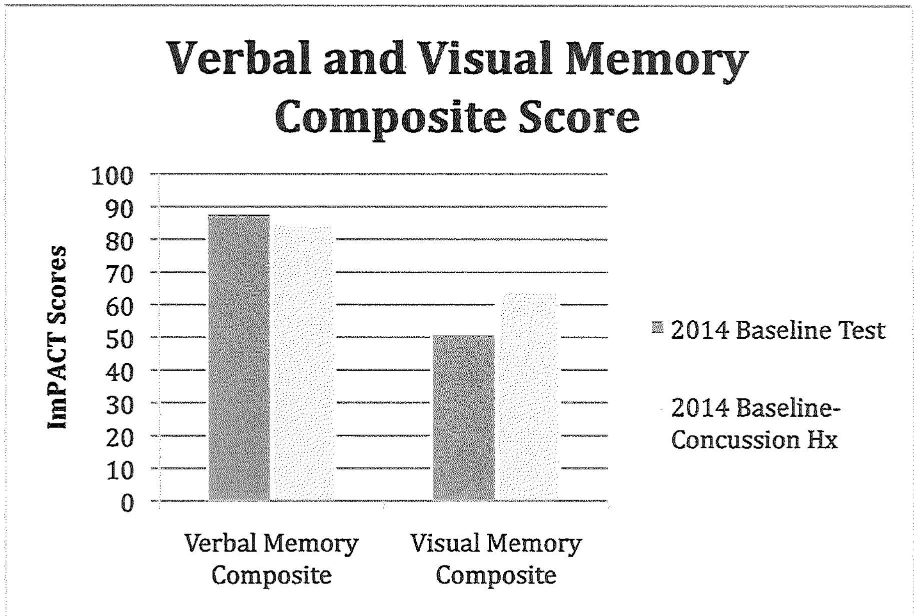
Chapter 5

Discussion

The present study investigated the effects a history of concussions has on neurocognitive impairments in collegiate wrestlers. The preliminary analysis of the baseline scores taken prior to season starting, displayed variability in verbal memory composite, visual memory composite, reaction time, impulse control, and visual motor processing. In addition, athletes with a history of three or more concussions had decreased baseline scores, specifically with verbal memory composite, visual memory composite, and reaction time scores. However, Broglio et al. (2006) suggested that a concussion history has minimal or no effect on computerized baseline concussion testing scores (Broglio, Ferrara, Piland, & Anderson, 2006). The findings in this study suggest that a concussion history does affect baseline concussion scores that can be detected using a computerized neurocognitive test. Athletes (n = 3) who sustained concussions after the initial baseline test for this study and established new baseline scores had slower reaction times, increased visual processing speed, increased verbal and visual memory composite scores. These results illustrate that athletes with a history of concussions may still have cognitive deficits, and athletes who have recent concussions may still be cognitively impaired despite being cleared to return to play.

Visual memory composite scores were lower compared to verbal memory composite scores in the baseline ImPACT tests. These results support research showing that athletes with a history of concussions have lingering deficits in memory (Iverson, Echemendia, Lamarre, Brooks, & Gaetz, 2012). In addition, reaction time baseline scores were unevenly distributed, emphasizing slower reaction time baseline scores. Baseline scores for impulse control were higher amongst the subjects. Visual motor speed baseline scores were slower as well. These results support findings in Covassin et al. (2008) with decreased verbal memory and reaction time scores in athletes with a history of concussions (Covassin et al., 2008). However, this study observed differences in athletes with a history of concussion with post-injury scores. It was not observed if baseline scores were affected by a history of concussions. The findings from this study differ from Covassin et al. because the effects of a history of concussion on baseline scores was shown to have decreases in verbal memory, visual memory, and reaction time scores. The decreased scores could suggest that the subconcussive blows sustained in wrestling prior to this baseline test may have affected cognitive function. Since it cannot be determined whether or not subconcussive blows caused low scores in visual memory and reaction time, there can only be assumptions made.

Two subjects had a previous history of concussions and ImPACT scores post-injury that were used to compare to the new baseline scores. It was shown that athletes with a history of three or more concussions had similar decreases in verbal memory composite and visual memory composite. One athlete suffered concussions two years prior to this study, and the previous baseline scores illustrated decreases in visual motor speed and slower reaction times. However, the baseline scores obtained for this study showed this athlete had increased visual motor speed and decreased his reaction time. The other athlete with a history of three or more concussions suffered his concussions several months prior to participating in this study, and he had a slower reaction time and decreased visual motor speed score. It could be concluded this athlete is two years later returning to the baseline score collected prior to the two concussions. The two athletes who had a history of four concussions had similar changes in verbal memory composite and visual memory composite, but differences in visual motor speed and reaction time (Figure 12, Figure 13, Figure 14). This could suggest that it could take an athlete months to years to return to normal cognitive function. Three athletes suffered a concussion after the baseline test was completed, and their post-injury scores were collected as well. These athletes had larger differences between baseline and post-injury reaction time and visual motor speed scores but had increases in verbal memory and visual memory composite scores. However, the athletes who suffered a concussion during the season had improved return-to-play scores compared to the athlete's original baseline scores. The differences in verbal and visual memory scores allude to unreliability of ImPACT in verbal and visual memory. This supports a recent study suggesting the test-retest reliability of ImPACT was better for visual motor speed and reaction time compared to visual and verbal memory (Resch et al., 2013). The improvements in the athlete's return-to-play scores compared to baseline scores could be contributed to factors that affected their performance on the baseline test. These factors could be lack of sleep, fatigue, or medications for ADD/ADHD. These factors are not proven to influence ImPACT scores, but they could contribute to an athlete not performing well on these tests or performing better.



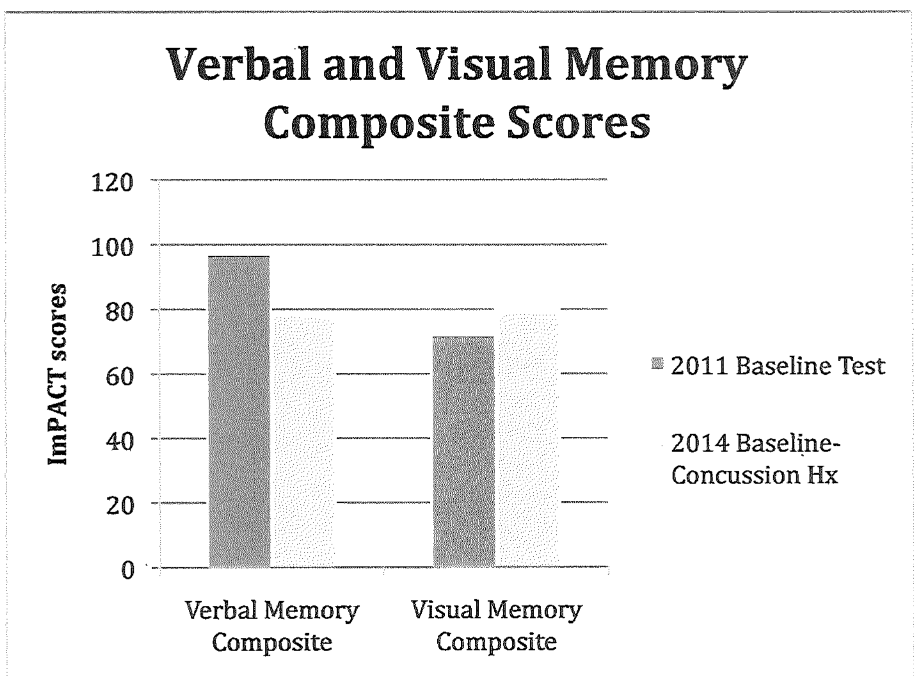
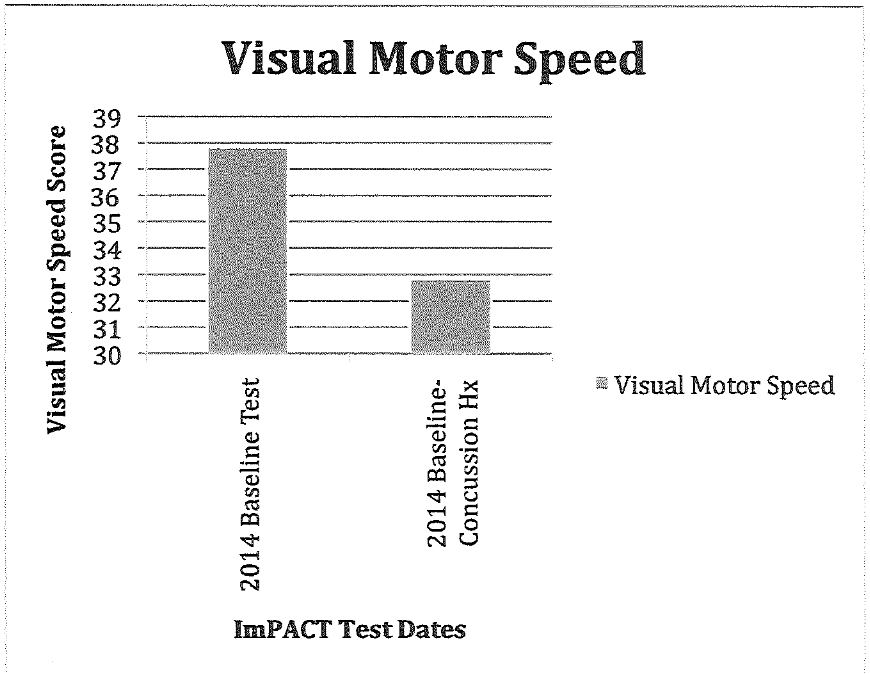


Figure 12: Visual and Verbal Memory Composite Scores for athletes with a history of 4 concussions. The top graph represents the athlete who had 2 concussions in 2014 and the bottom graph represents the athlete who had 4 concussions 2 years prior to baseline testing.



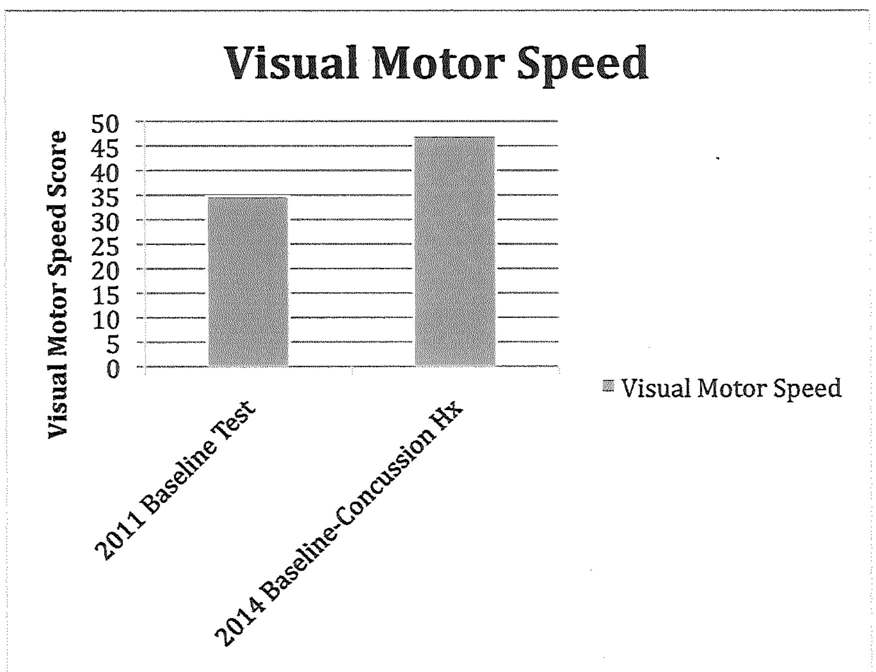
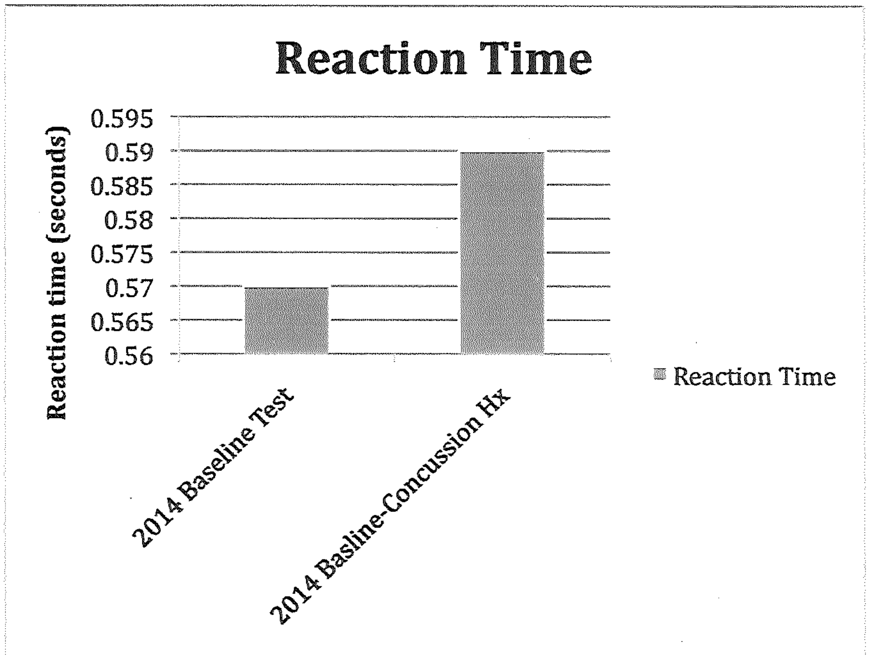


Figure 13: Visual Motor Speed of athletes with a history of 4 concussions. The top graph represents the athlete who had 2 concussions in 2014 and the bottom graph represents the athlete who had 4 concussions 2 years prior to baseline testing.



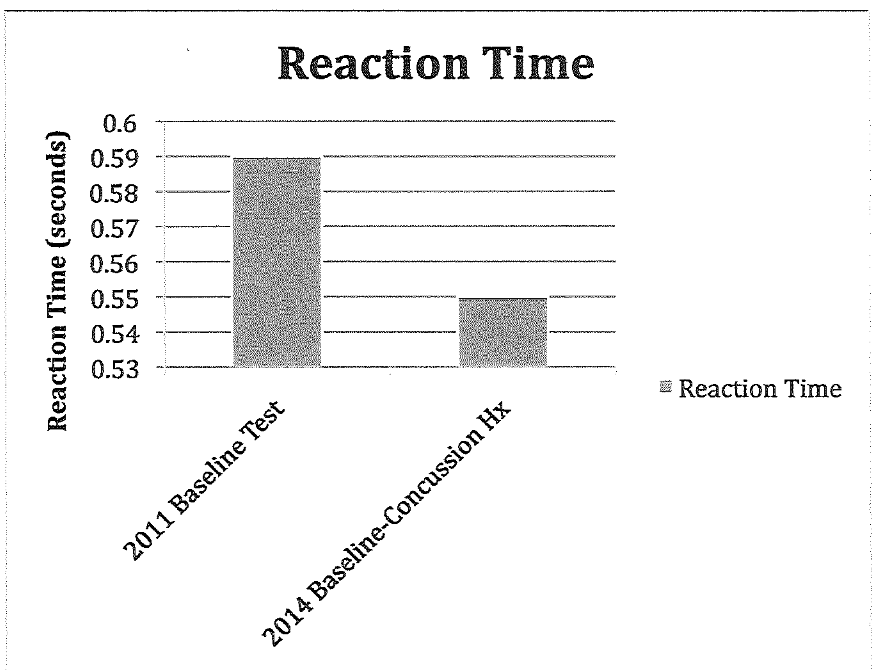


Figure 14: Reaction Time of athletes with a history of 4 concussions. The top graph represents the athlete who had 2 concussions in 2014 and the bottom graph represents the athlete who had 4 concussions 2 years prior to baseline testing.

These decreases in scores could have resulted from decreased white matter in the brain. Bazarian, Zhu, Blyth, Borrino, and Zong (2012) showed that in concussed athletes and subconcussed athletes there was decreased white matter in the brain causing cognitive impairments (Bazarian, Zhu, Blyth, Borrino, & Zhong, 2012). White matter is responsible for connecting neurons from one part of the brain to the other. If there are decreased areas of white matter, this could slow the nerve signaling process. The signal does not travel to the next neuron fast enough, causing a decrease in neuron function in the brain. The decreased neuron function could explain some of the slower functions such as reaction time and impulse control. Also, damage to the inferior longitudinal fasciculus is involved with semantics of language and verbal memory that could explain the decreased verbal memory and visual memory in those athletes with a history of concussions (Bazarian et al., 2012).

There were several limitations to this study. The first limitation was the small sample size, which created a decreased overall power for parametric statistics. The second limitation was that the ImPACT scores analyzed were non-gaussian distributed, meaning parametric statistics could not be used to analyze the data. However, these two limitations suggested non-parametric statistics should be used to analyze data. The non-gaussian distribution showed that concussion research should use non-parametric statistics to investigate concussion data. Another limitation was the inability to isolate subconcussive blows to determine if subconcussive blows had more effects on cognitive function compared to history of concussions. Future research should investigate these events separately in order to determine the deleterious effects on cognitive function.

This study was the first to investigate a history of concussions and the effects on cognitive function in a wrestling population. It is also the first study to suggest investigating concussion scores using non-parametric statistics. Non-parametric statistics analyze data based on parameters set by the data set. This type of statistics is imperative to use when evaluating data that is individualized. Also, the results support claims that athletes with a history of three or more concussions have cognitive deficits on baseline tests compared to athletes without a history of concussions which supports current literature (Covassin et al., 2013; Covassin et al., 2008). Based on limitations, this study suggests that concussion research should be investigated using non-parametric statistics due to the non-gaussian distributions. Every athlete reacts differently to concussions and subconcussive blows, and non-parametric statistics allows researchers to observe patterns based on the sample size, not what is considered the norm for the general population.

In conclusion, subconcussive blows may have a negative effect on cognitive function; a history of four concussions has deleterious effects on verbal memory, visual memory, reaction time, and visual motor speed. This study investigated the effects a history of concussions and subconcussive blows had on cognitive function in collegiate wrestlers. Future research should investigate whether or not subconcussive blows effects cognitive function over a season for athletes who participate in wrestling.

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Vita

Meredith Lynn Buskard was born in Huntington, New York, to Bruce and MaryPat Buskard. She graduated from Providence High School in North Carolina in 2008. The following autumn she attended Lynchburg College to study Athletic Training, and in May 2012 she was awarded her Bachelor of Science degree. She accepted a job as an athletic trainer at Belmont Abbey College in the fall of 2012. The following autumn she accepted a graduate assistantship at Appalachian State University and began to study toward a Master of Exercise Science. The Masters degree will be awarded in May 2015. In March 2015, Ms. Buskard accepted a job at IMG Academy as an Athletic Trainer. She resides in Bradenton, Florida working at IMG Academy.