2012-01-01

Brain Maturation in the Adolescent Athlete and It's Implication on Concussion Management

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by

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THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Rehabilitation Sciences

THE UNIVERSITY OF TEXAS AT EL PASO

May 2012

Acknowledgements

This thesis would not of been possible without the guidance, help and support from a special mentor, Dr. Anthony P. Salvatore. The supervision and support that he gave truly helped the progression of this thesis. Your patience, guidance and support are greatly appreciated.

A very special thanks to Dr. Bess Sirmon Fjordbak, Dr. Arthur Islas and all the students in UTEP's concussion management clinic. I am forever appreciative for all the support and help over the two years.

Of course, without the love and support from my husband, Mike, this thesis would have been impossible to complete. For all of the late meals and practice speeches you listened to, I am eternally grateful.

Jacqueline Picone

Abstract

As the adolescent brain develops, any event that interrupts the process, such as a concussion, may result in long-term academic and social effects (Dennis & Levin, 2004). To date, there is no specific assessment or protocol published that consider the cognitive and development of the adolescent brain when managing concussion (Patel, et al., 2005). ***Purpose***: to investigate whether there is a statistically significant difference between the composite scores and sub-test scores in the subtests on the ImPACT battery: Word Memory, Design Memory, X's and O's, Symbol Match, Color Match, and Three Letters, of high school male athletes between the ages of 13 to 15 and between the ages of 16-19. ***Method***: A between subject cross sectional design. The first group consists of adolescent athletes ages 13 and 15, and a second group consists of adolescent athletes between ages 16 and 19. Each athlete has previously taken the ImPACT battery as a baseline per requirement for participating in his chosen sport. A non-parametric Mann-Whitney U Test and parametric Independent sample t-test was used to determine whether there is a significant difference between the two groups. The dependent variables are the composite and subtest scores achieved on the 6 subtests on the ImPACT battery. The independent variable is the age difference between the two groups of athletes. ***Results*:** There is a statistically significant difference between the two groups on the following composite and subtest scores of the two groups: cognitive efficiency index (z=-2.534, p<.011); verbal memory composite (z=-2.232, p<.026); visual motor speed composite (z=-5.531, p<.000); reaction time composite (z=-5.022, p<.000); color match average correct reaction time (z=-3.758, p<.000); and three letters percent of total letters correct (z=-2.239, p<.025). Result suggests that an athlete's cognitive performance as a young adolescent is significantly different from his performance as an older adolescent as measured by the ImPACT test.

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Chapter 1: Introduction

Concussion management in high school level athletics is increasingly problematic. Young athletes all over the United States are in situations where they are at risk of suffering a concussion. According to Solomon and colleagues (2006), there are over one million high school football players in the United States alone, far more than the estimated number of collegiate or professional players. High school football players are at great risk of suffering from a head injury while playing the game (Solomon, Johnston, & Lovell, 2006). Solomon and colleagues (2006) cite Mueller (2001) stating that from 1984 to 1999 there were sixty-nine reported head-related football injuries that resulted in permanent disability. Of the sixty-nine injuries, sixty-three of those occurred in high school football games. More recently, Broglio and colleges (2009), report that high school football players represent the single largest group of athletes that have suffered from sport-related concussions. In a given year, 3.6% to 5.6% of the 1.2 million high school football athletes sustain concussions (Broglio, et al., 2009). In addition to these alarming numbers, 53% of concussed high school athletes are suspected of not reporting their injuries to medical personnel (Broglio, et al., 2009). Ultimately, the timely diagnosis and treatment of concussions in high school athletes are critical due to the vulnerability of adolescent's developing brain.

1.1 Concussion

Concussion, also known as a mild traumatic brain injury (mTBI), can be defined as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (McCroy, et al., 2009). A concussion may be caused by either a direct blow to the head, face, and neck or anywhere on the body with a force conveyed to the head. Even though young athletes may not experience direct helmet-to-helmet hits every play, they are still prone to suffering a concussion. Loss of consciousness is a common trademark of a concussion; however, an athlete may still suffer a concussion and never lose consciousness (Giza & Hovda, 2001). Other symptoms include but are not limited to: confusion, headaches, disorientation, dizziness, visual disturbances and memory difficulties (Giza, & Hovda, 2001). All of these symptoms, alone or accompanied but other symptoms can indicate concussion. A concussion results in neuropathological changes that are demonstrated through a functional disturbance of the brain rather than a structural injury (McCrory, Meeuwisse, Johnston, Dvorak, & Aubry, 2009). In other words, an athlete's ability to appropriately function in school, at home and on the field will be disrupted following a concussion.

As defined by McCrory and colleagues (2009), concussion management typically involves the evaluation of an assortment of behaviors: clinical symptoms, physical signs, behavior, balance, sleep and cognition. During the first international conference on concussions in sports, Aubry and colleagues (2001) discussed the somatic, cognitive and/or emotional symptoms one may experience when suffering from a concussion. They identify headaches, nausea, vomiting, drowsiness, numbness and/or tingling as other prevalent symptoms of a concussion. A concussed individual may experience dizziness, problems with balance, difficulty sleeping or even excessive sleeping. Sensitivity to light and noise and feeling slowed down or mentally foggy are commonly reported as well. They further report patients may experience difficulty concentrating, difficulty with memory, and may feel more emotional than usual. Some changes in personality may be evident through increased irritability, sadness or nervousness.

Adolescents suffering from any of these symptoms may exhibit difficulty in daily functional activities such as participating in class discussion, comprehension of classroom material, performance on standardized tests or their participation in sports. It is important to note that even if the athlete is able to engage in fundamental activities, such as participating in practice or game play, this does not automatically suggest that the athlete has not suffered a concussion. Therefore, any suspicion of a concussion should be followed by an assessment of the athlete's cognitive-communicative and neurological status.

1.2 The Developing Brain

As the brain is developing, any event that interrupts the developmental process may result in long lasting effects (Devin, & Levin, 2004). Based on their rat model, Giza and Hovda, (2001) conclude that any insult to the brain will lead to impaired neural plasticity. Plasticity refers to the nervous system's ability to reorganize itself: ultimately changing the functioning of the nervous system (Kolb, 1995). Dennis and Levin (2004) agree and add that plasticity enables the young brain to develop new functions, skills and knowledge. They explain two types of plasticity seen in the human brain: plasticity for recovery and plasticity for development. They describe plasticity for recovery as the re-organization of functions that were disrupted by an insult to the brain; for example, a slowed reaction time or processing speed. Plasticity for development is described as a process that supports the adolescent brain in acquiring new functions, skills and knowledge. They suggest that plasticity for recovery coexists with plasticity for development in the adolescent brain, both of which contribute to long-term cognitive-communicative functions (Dennis & Levin, 2004). Any insult to the brain may result in long lasting effects such as impaired processing skills, memory impairment and learning.

The human brain develops over a long period of time, from birth until young adulthood (Meehan, et al., 2011). The prolonged growth of the human brain is associated with a large cortex and pre frontal cortical area (Johnson, 2001). The pre frontal cortex is described as a "later developing structure", indicating that it fully matures at the end stages of development

(Johnson, 2001). Fuster (2001) reports evidence from imaging studies that the pre frontal cortex is not fully mature until late adolescence. The pre frontal cortex is critical for higher functioning cognitive skills, such as propositional speech, reasoning, learning, problem solving and language that develop over time (Fuster, 2001).

The rate of brain development is different for everyone. Giedd and colleagues (1999) explain; changes in the cortical gray matter are correlated with specific ages: gray matter in the frontal lobe increased during pre-adolescence (ages 10 to approximately 14 years) and declined during post-adolescence (16 years or older) resulting in a decrease in volume across this age span. Johnson (2001) explains the most rapid burst of synapse formation and the peak of density of synapses in the frontal region of the brain occur at different ages in different stages across individuals (Johnson, 2001). He further explains that white matter reflects interregional communication in the developing brain and continues through adolescence before it peaks in adulthood.

The work of Chapman and Sparks (2004) further highlights the importance of the development of the pre-frontal cortex by assessing the cognitive abilities in normal adolescents. They tested macro-level processing of information: the ability to store bits and pieces of information and preserve the original meaning. They point out that macro-level processing of information increases with age. For instance, investigators found that elementary school children summarize information by deleting less important details while holding onto important information. Conversely, high school and college students usually combine ideas from different paragraphs and change information into more comprehensive statements. This allows the older students to express more information in fewer words when compared to elementary school children. This process develops during the adolescent years and is a significant factor in the development of critical thinking. Any damage to the brain during this developmental process can adversely impact a person's academic, employment and social success.

There are many ways to analyze the development of the brain. Giedd, et al., (1999) discussed pediatric neuroimaging studies that show there is a linear decrease in cortical gray matter and an increase in white matter from age four through age twenty. Their results support the hypothesis that the adolescent brain is constantly changing and developing (Giedd, et al.,1999). Further, Ylvisaker & Szekeres, (1989) point out that following a brain injury executive functions are disrupted. Such disruptions result in an adolescents ability to engage in goal-directed behaviors necessary to initiate activities and to monitor tasks. These skills are extremely important in completing daily tasks such as being successful in school and participating as a member of a team.

Based upon the review of data above it is evident that the adolescent years are a critical time for the development of cognitive-communicative abilities. Because of the critical nature of this development process, a prompt and effective assessment and treatment of the student-athlete following a concussion is crucial in avoiding long-term cognitive impairment.

1.3 The Impacts Concussions Have on Cognitive-Communicative Functioning In High School Student-Athletes

According to Russell (1993), adolescents may experience approximately six cognitive deficits when experiencing a mild to severe traumatic brain injury. These areas of deficit include: attention/concentration, memory, speed of processing information, organizing processes, reasoning and executive function. Lovell and colleagues (2003) found that high school athletes with mild concussions displayed significant declines in memory processes in comparison to a group of matched high school athletes with no concussion. They also found that high school athletes suffering from mild concussions show measureable memory declines at least 7 days post injury (Lovell, et al. 2003). In comparison to collegiate athletes, Field and colleagues (2003) report that high school athletes with concussions show more impaired memory performance. Specifically the high school athletes' performances were significantly inferior to college students 7 days post injury. The college athletes demonstrated accepted levels of performance by the 3rd day following a concussion. These findings suggest that it takes high school athletes longer to recover from a mild concussion compared to collegiate athletes.

1.1.3 Duration of Symptoms Vary Across Children and Adults

Field and colleagues (2003) evaluated symptoms and cognitive recovery patterns following a concussion in high school and collegiate athletes. They found that high school athletes had prolonged memory dysfunction in comparison to the collegiate athletes. Even at 7 days post injury, the high school athletes continued to exhibit an overall decreased cognitive-communicative performance where as the collegiate athletes demonstrated cognitive improvements between 3 to 5 days post injury. Lovell and his colleagues (2003) found similar findings. They assessed high school athletes who sustained a concussion. They evaluated memory dysfunction and self-reported symptoms utilizing the ImPACT test. They concluded that there was a prolonged memory decline in high school athletes at least 7 days post-injury. In contrast to the decline in memory over a 7-day period they found that high school athletes report a decline in symptoms around the 4th day post injury. McClincy and colleagues (2006) support these findings with their study. They tested 104 high school and college athletes using the ImPACT test, a computerized test assessing cognitive functions. They concluded that even though athletes were reporting less, or no, symptoms, they were continued to exhibit cognitive deficits.

Overall, the studies mentioned above indicate that age is a factor in terms of the severity of cognitive functions following a concussion and the duration of symptoms. Maturation appears to be a key consideration in management of concussion.

1.4 Current Concussion Management Protocol

Current concussion management protocols have multiple phases (Lee, 2009). Initially, collecting pre-season data of the athlete is important. This includes the athlete's performance on a standardized assessment of cognitive-linguistic functioning pre-concussion (Lee, 2009). This is typically done during the athlete's initial pre-season health physical as a freshman. Before an athlete who is suspected of sustaining a concussion is retested, they are removed from the game and advised to rest. McCrory and colleagues (2009) highlight the importance of physical and cognitive rest until symptoms are resolved. Then, the athlete will sit for the same standardized test he or she initially took as a pre-season assessment. The athlete will continue to retake the standardized battery until he or she performs as they did on their pre-season assessment. When the athlete returns to their pre-season performance on the standardized battery and is asymptomatic, they can begin the return to play protocol (McCrory, et al. 2009). The return to play protocol involves stages. The athlete cannot proceed to the next stage if he or she becomes symptomatic. Once they are asymptomatic, they can proceed to the following stage until they are ready to return to play. The stages occur in the following order: no activity, light aerobic exercise, sport-specific exercise, non-contact training drills, full contact practice and finally return to play (McCrory, et al., 2009).

Based upon the data reviewed and the observations made by experts in the field of concussion management, the management of sport-related concussions needs to be specialized for adolescents when compared to collegiate and professional athletes in order for clinicians to make safe return to place decisions. To date, there is no specific assessment or protocol published that consider the cognitive, psychosocial and physical development of the adolescent population when managing sports-related concussions (Patel et al., 2005). As a society it is important to understand that the management of sport-related concussions needs to be specialized for adolescents when compared to collegiate and professional athletes. Adolescent brains are continuously developing and take longer to recover from concussions. Current protocol of concussion management suggest return to play decisions be based on, although not solely, on the athlete's ability to return to his or her baseline performance and be asymptomatic. However, Schatz (2010) points out that there are no current protocols for how frequently baseline assessments should be repeated per athlete. The call for establishing test-retest reliability over time intervals that are clinically relevant is increasingly important. Patel and colleagues (2005) argue that the current concussion management protocol does not account for the development process of the adolescent brain. Thus, returning to baseline may not reflect a full recovery. For adolescents, conducting multiple testing of baseline cognitive performance may result in a more reliable and accurate measure of their current cognitive performance. Furthermore, an understanding of the impact of a concussion on the normal development of the brain in adolescents is needed. This data may provide guidance for specialized concussion management protocol for adolescent population.

1.5 Second Impact Syndrome

High school athletes' returning to the classroom and play safely is the ultimate goal. As previously discussed, a concussion interrupts many cognitive processes that interfere with daily functioning in school, at home and on the field. However, Second Impact Syndrome (SIS) is another reason why returning to play safely is a major concern. Bey and Ostick (2009) explain that SIS refers to an athlete receiving a second blow to the head while still experiencing post-concussive symptoms from the first blow to the head. They further clarify that an athlete who sustains an initial concussion may develop cerebral edema, experience memory problems, disorientation and headache. The brain has an auto regulatory system that compensates for the physiological stress and it helps protect against massive swelling. The result of the brain using the auto regulatory system is decreased cerebral blood flow, which leads to accumulation of lactate and intracellular acidosis. This also involves decreased protein synthesis and reduced oxidative capacity (Bey, & Ostick, 2009). Overall, this makes the brain more susceptible to death after even a mild second insult to the brain. When the athlete sustains a "second impact" the brain's auto regulatory system becomes impaired and is unable to properly monitor the intracranial and cerebral perfusion pressures. SIS is devastating to the immature brain, leaving the young athlete with symptoms that are unable to return from, or possibly death.

SIS is something that can be prevented with the proper concussion management protocol: ensuring that athletes return to play safely. As stated above, the current concussion management protocol does not take into account the developing brain. Many cognitive tests; such as ImPACT, need a protocol to account for how the developing brain may look on a cognitive assessment.

1.6 Purpose of Study

The purpose of this investigation is to determine whether a statistically significant difference in cognitive performance on the ImPACT battery exists between two age groups of high school athletes, ages 13 -15 and 16 to 19. If a difference is found then a recommendation that athletes be tested as freshman and then as juniors may be a reasonable recommendation due to the age groups presented in this study.

Chapter 2: Method

2.1 Participants

Existing test performance data of high school athletes in the El Paso, Texas area was selected for this study. Baseline data was previously collected between 2008 and 2010 from over 400 male athletes referred to the Concussion Management Clinic (CMC) - UTEP. Participants' age range from 13 years of age to 19 years of age. Participants were excluded from this study based on the following: history of concussion, diagnosis of a learning disability, ADD/hyperactivity, attended special education classes, received speech therapy, repeating grades of education, treated for any of the following: headaches, migraines, meningitis, substance abuse, psychiatry, epilepsy or underwent brain surgery. The final sample of participants resulted in 404 high school male athletes who played for one of the following sports: football, basketball, soccer, wrestling, baseball or track and field.

Table 1.1 Frequencies of Participants

Age of Participants	Frequency
13	6
14	97
15	120
16	95
17	79
18	5
19	2
Total Participants	**404**

2.2 Statistical Analysis

Descriptive and non-parametric statistical analyses are reported for composite and sub-test scores from the ImPACT test that assess cognitive-communicative abilities of verbal memory, visual memory, reaction time, processing speed, attention, symptoms, and impulse control. The composite scores are Verbal Memory Composite (VerMC), Visual Memory Composite (VisMC), Visual Motor Speed Composite (VMSC), Reaction Time Composite (RTC) and Impulse Control Composite (ICC). The subtest scores that make up the composite scores are: word memory hits immediate, word memory hits delay, word memory total percent correct, design memory hits immediate, design memory hits delay, design memory total percent correct, X's and O's total correct memory, symbol match total correct visible, symbol match total correct hidden, color match total correct, color match average correct reaction time and three letters percent of total letters correct. Finally, the Total Symptom Score (TSS) is a self-reported symptom inventory by the athletes within twenty-four hours of sitting for the test. To compare the two groups, a nonparametric Mann-Whitney *U* Test and parametric Independent sample t-Test was used to determine whether there are statistically significant differences between the two groups on each of the different composite scores and subtest scores. The dependent variables are the composite and subtest scores achieved on the ImPACT battery. The independent variable is age: the Young Group consists of from 13 to 15 years of age compared to the Older Group consisting of 16 to 19 years of age.

2.3 Assessment Instrument

The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT, Applications, Inc., Pittsburgh, PA) is a computer-based testing instrument designed specifically for assessing and managing sports-related concussion. The battery is divided into three sections:

Demographic information, Self-Reported Symptom Inventory, and six neurocognitive test modules. The battery is available in 21 different languages. It takes between 30 to 40 minutes to complete the battery.

2.4 Research Design

This study is a replication of the ImPACT's normative data and is a between subject cross sectional design with two groups of participants. Group 1, the Young Group, consists of athletes between the ages of thirteen and fifteen. The Older Group consists of high school athletes between the ages of 16 and 19. Each athlete has previously taken the ImPACT battery during preseason as a requirement for participating in his chosen sport. Each subtest on the ImPACT battery produces raw scores, which reflects the participant's cognitive performance in verbal memory, visual memory, reaction time, processing speed, and impulse control. The raw scores for each subtest will be compared between the two groups.

The raw scores for each subtests on the ImPACT battery: Word Memory, Design Memory, X's and O's, Symbol Match, Color Match, and Three Letters are generated by the ImPACT's software. These raw scores were entered into a database for analysis.

Subtests: the Word Memory and the Design Memory subtest are divided into 7 scores: hits (immediate), correct distracters (immediate), learning percent correct, hits (delay), correct distracters (delay), delayed memory percentage correct and total percent correct. The X's and O's is the third subtest measured; divided into 5 scores: total correct (memory), total correct (interference), reaction time of the average correct (interference), total incorrect (interference) and reaction time of the average incorrect (interference). The Symbol Match subtest is divided into 4 scores: total correct (visible), reaction time of average correct (visible), total correct (hidden) and reaction time of average correct (hidden). The Color Match subtest is divided into 4 scores: total correct, reaction time of average correct, total commissions and reaction time of the average commissions. The last subtest, Recalling of Three Letters, is divided into 6 different scores: total sequence correct, total letter correct, percentage of total letters correct, average time to first click, average counted and average counted correctly.

Composite scores are an average of the subtest scores that represent the athlete's attention, memory, reaction time, impulsivity and processing abilities. There are 5 composite scores:

(1) Verbal memory composite (VerMC) score is an average score of the following subtest scores: total memory percent correct, on the symbol match subtest: total correct hidden symbols and on the three letters subtest: total percent of total letters correct. (2) The visual memory composite (VisMC) score is comprised of total percent correct on the design memory task, and total correct memory score on the X's and O's task. (3) The visual motor speed composite (VisMSC) score is made up of the total correct on subtest X's and O's and an average counted correctly on the three letters subtest. (4) The reaction time composite (RTC) score is comprised of the reaction time with correct responses on the X's and O's, color match and symbol match subtests. (5) The impulse control composite (ICC) score is comprised of total incorrect response on the X's and O's subtest and total commissions on the color match subtest.

A higher number on each of the subtest scores will indicate a better performance on the composite scores, except on the impulse control composite score. For this score, it is better to receive a lower score, indicating the athlete was less impulsive.

The Cognitive Efficiency Index score is a derived score comprised of the participant's performance on the Symbol Match subtest indicating a balance between speed and accuracy.

For the purpose of this investigation, there were a total of 19 scores reported and analyzed from the ImPACT battery. Specifically, all 5 composite scores were used for analysis. The participants' performances on 13 subtest scores that comprise the 5 composite scores were analyzed (totaling to 19 raw scores that were analyzed).

It is important to highlight that the ImPACT test has more subtest scores that comprise each of the composite score, however, they were not all selected for the purpose of this study strictly due to time restraints. The subtest scores that were selected specifically for the purpose of this study is mentioned and described above.

Chapter 3: Results

A non-parametric analysis and parametric analysis was conducted to compare the scores between the Young Group (group 1: ages between 13-15) and Older Group (group 2: ages between 16-19). This section is divided into the non-parametric analysis (Mann-Whitney U results) and the parametric analysis (Independent t-test results). Within each section, the results will be reported in the following order: composite scores then subtest scores that comprise each composite score. For each analysis, the expected direction is that the Older Group (group 2) of student athletes will do better than the Younger Group (group 1) of student athletes.

Mann-Whitney U

A Mann-Whitney U test was conducted on multiple composite and subtest scores to evaluate the hypothesis that there will be no statistical difference on the ImPACT battery between the Young Group (high school athletes between the ages of 13 and 15) and the Older Group (high school athletes between the ages of 16 and 19).

Mean rank scores, p values and z values are reported. Mean ranks scores are explained: all scores for both groups are grouped together into one column. The scores are then ranked from lowest to highest. Once the ranks are assigned, the scores are then split back into the group they belong to. At this point, the mean of the ranks in each group is calculated. The test is done to see if there is a statistically significant difference in the mean ranks for each group. Each composite score is reported with the subtest scores that comprise that composite score to follow.

The results for VerMC score were in the expected direction and statistically significant ($z = -2.232$, $p<.026$). The Young Group had an average mean rank of 190.83 and the Older Group had an average mean rank of 216.88, indicating that the Older Group performed better than the Young Group.

The results for the following subtests help make up the VerMC score and the performance on each of the subtests is described: Word Memory Total Percent Correct: Performance was in the expected direction but was not statistically significant, $z=-1.757$, $p>.079$. The Young Group had an average mean rank of 193.38 and the Older Group had an average mean rank of 213.73. The results for subtest score Symbol Match Total Correct Hidden were in the expected direction but were not statistically significant, $z=-1.469$, $p>.142$. The Young Group had an average mean rank of 194.91 and the Older Group had an average mean rank of 211.86. The results for subtest score Three Letters Percent Of Total Letters Correct was in the expected direction and statistically significant, $z=-2.239$, $p<.025$. The Young Group had an average mean rank of 191.28 and the Older Group had an average mean rank of 216.33.

The results for VisMC score were in the expected direction but were not statistically significant, $z= -.394$, $p=.693$. The Young Group had an average mean rank of 200.44 and the Older Group had an average mean rank of 205.04, indicating that both groups scored within the same range.

The results for the following subtests help make up the VisMC score and the performance on each of the subtests is describe: X's and O's Total Correct Memory: Performance was not in the expected direction and not statistically significant, $z=-.151$, $p=.880$. The Young Group had an average mean rank of 203.28 and the Older Group had an average mean rank of 201.73. The results for subtest Design Memory Total Percent Correct were in the expected direction but were not statistically significant, $z=-1.128$, p>.279. The Young Group had an average mean rank of

196.60 and the Older Group had an average mean rank of 209.77, indicating that the Older Group performed significantly higher than the Younger Group.

The results for VisMSC score were in the expected direction and statistically significant, z=-5.531, p<.000. The Young Group had an average mean rank of 173.55 and the Older Group had an average mean rank of 238.17, indicating that the Older Group performed significantly higher than the Younger Group.

The athletes performance on subtest X's and O's Total Correct Memory make up both composite scores: VisMC and VisMSC. Therefore, results are described above. Further, the results for the subtests Three Letters Percent Of Total Letters Correct make up both composite scores of VerMC and VisMSC. Therefore, results are described above.

The results for RTC score were not in the expected direction but were statistically significant, z=-5.022, p<.000. The Young Group had an average mean rank of 228.76 and the Older Group had an average mean rank of 170.15, indicating that the Young Group responded faster to stimuli during the X's and O's, Color Match and Symbol Match activities on the test in comparison to Older Group.

The subtest score X's and O's Total Memory were reported previously and contribute to the RTC score. The subtest score of Color Match Average Correct Reaction Time was not in the expected direction but was statistically significant, z=-3.758, p<.000. The Young Group had an average mean rank score of 222.16 and the Older Group had an average mean rank score of 178.28.

The results for the CEI score were in the expected direction and were statistically significant, z=-2.534, p<.011. The Young Group had an average mean rank of 189.24 and the

Older Group had an average mean rank of 218.84, indicating that the Older Group had a higher ratio between reaction time and accuracy in comparison to Younger Group.

The results for the ICC score were in the expected direction but were not statistically significant, z=-.681,p=.496 The Young Group had an average mean rank of 198.95 and the Older Group had an average mean rank of 206.88.

The results for TSS were in the expected direction and was statistically significant, z=-2.093, p<.036. The Young Group had an average mean rank of 191.64 and the Older Group had an average mean rank of 215.88, indicating that the Older Group reported a higher symptom score in comparison to the Younger Group.

Other subtest scores include the following: The results for the subtest Word Memory Hits Immediate were in the expected direction but were not statistically significant, z=-.563, p=.573. The Young Group had an average mean rank of 199.98 and the Older Group had an average mean rank of 205.61. The results for the subtest, Word Memory Hits Delay were in the expected direction but were not statistically significant, z=-1.560, p>.079. The Young Group had an average mean rank of 194.57 and the Older Group had an average mean rank of 212.27. The results of the subtest Design Memory Hits Immediate were in the expected direction but were not statistically significant, z=-1.472, p>.141. The Young Group had an average mean rank score of 195.04 and the Older Group had an average mean rank of 211.69. The results of the subtest, Design Memory Hits Delay were in the expected direction but were not statistically significant, z=-.271, p=.786. The young Group had an average mean rank score of 201.11 and the Older Group had an average mean rank score of 204.21. The results of subtest, Symbol Match Total Correct Visible was not in the expected direction but were not statistically significant, z=-.219, *p*=.827. The Young Group had an average mean rank of 203.13 and the Older Group had an average mean rank of 201.73. The results of subtest, Symbol Match Total Correct Hidden was in the expected direction but were not statistically significant, *z*=-1.469, *p*>.142. The Young Group had an average mean rank of 194.91 and the Older Group had an average mean rank of 211.86. The results of subtest, The Color Match Total Correct was in the expected direction and was statistically significant, *z*=-1.065, *p*>.287. The Young Group had an average mean rank of 198.47 and the Older Group had an average mean rank of 207.47.

Independent Sample t-test

An independent-samples t-test was conducted to compare the raw scores on specific composite and subtest scores on the ImPACT battery between the Young Group (high school male athletes of the ages between thirteen and fifteen: group 1) to the Older Group (high school male athletes of the ages between sixteen and nineteen: group 2). The confidence intervals reported for the purpose of this study include a 95% interval, indicating that with this degree of confidence, the population mean is within this interval. Results are reported in the following order: composite scores then subtests scores that comprise each composite score. The expected results are that the older group of student-athletes would perform better than the younger group.

There was a significant difference for VerMC scores between the Young Group (M=83.59, SD=9.25); and the Older Group (M=85.79, SD=9.04); t (388.5) = 2.41, *p*=.017 (two-tailed). These results are suggesting that the Older Group performed better than the Young Group in the abilities of immediate and delayed memory of printed words.

The results for the following subtest help make up the composite score VerMC and the performance on each of the subtests are described: there was a significant difference for Three

Letters Percent Of Total Letters Correct subtest scores between the Young Group (M= 88.2, SD= 12.31) and the Older Group (M=.90.7, SD=11.25); t (396.36) =-2.21, *p*=.028 (two-tailed). The difference in the means (mean difference= -2.59, 95% CI: -4.90 to -.282) was very small. These results suggest that the Older Group performed significantly higher than the Young Group when using skills of working memory. There was not a significant difference for Word Memory Total Percent Correct subtest score between the Young Group (M=93.121, SD=5.95); and the Older Group (M=93.88, SD=6.25); t (376.82) =-1.24, *p*=. 217 (two-tailed). There was also no significant difference for the Symbol Match Total Correct Hidden subtest score between the Young Group (M=6.26, SD=1.94); and the Older Group (M=6.56, SD=1.799); t (394.7) = -1.575, *p* = .116 (two-tailed).

Further, there was no significant difference for the VisMC score between the Young Group (M=74.322, SD=11.91); and the Older Group (M=75.03, SD=12.43); t (378.19) = -.582, *p* = .561 (two-tailed). However, the differences in the means (mean difference= -.7102, 95% CI: -3.11 – 1.690) were small.

The following subtest scores make up the VisMC composite score and the performance on each of the subtests is described: there was no significant difference for the Design Memory Total Percent Correct subtest score between the Young Group (M=82.19, SD= 10.98) and the Older Group (M=83.41, SD=11.01); t (384.61) = -1.106, *p* = .270 (two-tailed). The differences in the means (mean difference= -1.23, 95% CI: -3.380 - .9470) were small. Even more so, there was no significant difference for the X's and O's Total Correct Memory subtest score that helps make the "visual memory composite" score between the Young Group (M= 7.99, SD= 2.324) and the Older Group (M= 8.00, SD=2.380); t (381.29) = -.038, *p* =.970 (two-tailed). The differences in the means (mean difference= -.009, 95% CI: -.472 - .454) were also small.

There was a statistically significant difference for VisMSC scores between the Young Group (M= 32.56, SD=6.19) and the Older Group (M=36.01, SD=6.22); t (384.271) = -5.65, *p*= .000 (two-tailed). The difference in the means (mean difference=-3.51, 95% CI: -4.73 to -2.29) was large. These results suggest that the Older Group scored significantly higher than the Younger Group on tasks involving cognitive abilities of attention, concentration, working memory, visual processing speed and reaction time.

The subtest scores that make up the VisMSC were previously reported: X's and O's Total Percent Correct, under the VisMC scores; that shows no significant difference between the Young Group (M= 7.99, SD= 2.324) and the Older Group (M= 8.00, SD=2.380); t (381.29) = -.038, *p* =.970 (two-tailed). The differences in the means (mean difference= -.009, 95% CI: -.472 - .454) were small.

There was a significant difference for RTC scores between the Young Group (M=. 612, SD=.077) and the Older Group (M=.576, SD=.065); t(401.5) =5.06, *p*= .000 (two-tailed). The difference in the means (mean difference=. 036, 95% CI: .023 to .049) was very small. These results indicate that the Older Group is significantly faster when responding to chosen stimuli.

The following subtest scores help make up the RTC score and the performance on each is described: there was a statistically significant difference for the Color Match Average Correct

Reaction Time subtest scores between the Young Group (M= 8.34, SD=1.56) and the Older Group (M=8.64, SD=.959); t(396.4) =2.22, *p*=.027 (two-tailed). The difference in the means (mean difference= .034, 95% CI: .004 to .065) was very small. These results indicate that the Older Group out performed the Younger Group in the ability to match colors within an appropriate response rate. These abilities contribute to the composite score of RTC and ICC.

Other subtest scores that make up the RTC score include X's and O's Average Correct and Symbol Match Average Correct. Both of these subtest scores were not calculated during the time of this study.

There was a statistical significant difference for the CEI score between the Young Group (M = .3446, SD = .1302); and the Older Group (M = .38811, SD = .12582); t (390.037) = -2.857, *p* = .005 (two-tailed) .The differences in the means (mean difference = -.03653, 95% CI: -.06167 to -.01139) was small. These results suggest that Older Group (ages sixteen to nineteen) was faster and more accurate in comparison to the Younger Group (ages thirteen to fifteen).

Table 2.1 Composite Score Results

Composite Scores	Mann Whitney U Results	Independent Sample t-Test Results	Significant
Verbal Memory Composite	$p<.026$	$p<.017$	Significant
Visual Memory Composite	$p=.693$	$p=.561$	Not Significant
Visual Motor Speed Composite	$p<.000$	$p<.000$	Significant
Reaction Time Composite*	$p<.000$	$p<.000$	Significant
Impulse Control Composite	$p=.496$	$p=.496$	Not Significant

Table 2.2 Subtest Score Results

Sub-Test Scores	Mann Whitney U Results	Independent Sample t-Test Results	Significant
Cognitive Efficiency Index	$p<.011$	$p<.005$	Significant
Total symptom score	$p<.036$	$p>.103$	*Significant only in Mann-Whitney U
Word Memory Hits (Immediate)	$p=.573$	$p=.596$	Not Significant
Word Memory Hits (Delay)	$p>.146$	$p>.119$	Not Significant
Word Memory Total Percent Correct	$p>.079$	$p>.217$	Not Significant

Table 2.3 Subtest Score Results

Sub-Test Scores	Mann Whitney U Results	Independent Sample t-Test Results	Significant
Design Memory Hits (Immediate)	$p>.141$	$p>.168$	Not Significant
Design Memory Hits (Delay)	$p=.786$	$p=.702$	Not Significant
Design Memory Total Percent Correct	$p>.279$	$p>.270$	Not Significant
X's and O's Total Memory Correct	$p=.880$	$p=.970$	Not Significant
Symbol Match Total Correct (Visible)	$p=.827$	$p=.912$	Not Significant

Table 2.4 Subtest Score Results

Sub-Test Scores	Mann Whitney U Results	Independent Sample t-Test Results	Significant
Symbol Match Total Correct (Hidden)	*p*>.142	*p*>.116	Not Significant
Color Match Total Correct	*p*>.287	*p*>.057	Not Significant
Color Match Avg. Correct Reaction Time*	*p*<.000	*p*<.027	Significant
Three Letters Percent of Total Letters Correct	*p*<.025	*p*<.028	Significant

Chapter 4: Discussion

The research question asked is there a statistically significant difference in cognitive performance on the ImPACT battery between high school athletes between the ages of thirteen to fifteen and sixteen to nineteen? Through descriptive parametric and nonparametric analysis, the findings show a statistically significant difference in 3 out of the 5 composite scores and 3 out of the 14 subtest scores between the Young Group and the Older Group. These findings are consistent with the previously published data that reports that older athletes do better than the younger athletes on the ImPACT test. The present results are consistent with the ImPACT's normative data which shows that the average scores on the ImPACT increase across age (ImPACT, Applications, Inc., Pittsburgh, PA). The present findings replicate the normative data of the ImPACT and extend this data to a sample of high school athletes from the southwest border region. However, it differs from the ImPACT's normative data and other studies in two ways: (1) No history of concussion was reported by participants or any of the exclusion criteria mentioned previously. (2) All participants in the current study took the ImPACT as a baseline assessment for the first time. They were not exposed to the test prior; eliminating the concern of "learning the test".

These findings have major clinical implications. One important clinical question is whether one baseline assessment is adequate for a clinician to make return-to-play decisions for high school student athletes. Return to play decisions is dependent upon the athlete returning to his baseline performance. With the current study's results, it would be reasonable to expect the athlete will out perform his baseline performance if he were to become concussed approximately two years after the date of his baseline assessment. The Concussion Clinic at the University of Texas at El Paso has seen this exact situation multiple times. Athletes were tested as freshmen (approximately 14 years of age) and would become concussed as a late sophomore or junior (approximately 16 years old). On their first assessment post concussion, athletes would out perform their previous baseline assessment, which was taken approximately two years previously. Return to play decisions became difficult to make and even more complicated to explain to the athlete and his athlete trainer and/or coach.

One explanation for the statistically significant difference assessed between the Young Group and the Older Group is brain maturation. These results were anticipated because the normative data for the ImPACT shows differences across age groups. Of course brain maturation is accompanied by academic and life experiences. The demands of junior and senior class work in high school increase the demands on working memory and executive behavior. When assessing a young athlete the brain is continuing to develop with a continuing improvement in performance regarding cognitive abilities of verbal memory, visual memory, processing speed and reaction time. All of these cognitive abilities were seen in the composite and subtest scores (VerMC, VisMSC, RTC, CEI, TSS, Color Match Avg. Correct Reaction Time and Three Letters Percent of Total Letters Correct) that proved to be significantly different between the Young Group and the Older Group, which were in favor of the Older Group.

It is important to note that return to play decisions should be based not only on a cognitive test but multiple factors that affect the athlete. Athletic trainers and other personnel administering evaluations to assess concussions in young athletes should be aware of the role brain maturation plays in high school athletes who are not concussed and expect the same on high school athletes who are. Multiple baseline assessment of the high school athletes is recommended to account for safe return to play practice.

The present study recommends the establishment of a protocol that implements preseason and postseason concussion evaluations. Such pre and postseason testing would probably help control for maturation and repeated testing over time. Testing at the beginning and end of each season would provide the clinician with more current and individualized data when making return to play decisions if this adolescent becomes concussed. Of course, preseason and postseason assessment might suggest that the athlete would be learning the test, instead of demonstrating true performance. An alternative to the suggested protocol might be to have the athletes assessed as freshmen (first year on the high school team; between the ages of 13-15) and again at juniors (between the ages of 16-19). This will allow for a more individualized approach for high school athletes in need of concussion management.

This study does have limitations. Demographic information and history of concussion are self-reported variables that can greatly influence the results of the participants' performance on the ImPACT battery. For example, the possibility that the participants may have failed to report a history of concussion or any of the exclusion criteria may alter the test results. Additionally, participants' history, or stress of daily life can also change the participants' performance on the ImPACT battery. The testing site, time of day when testing was administered, and time of the year may interfere with the participants' true performance.

This study was restricted to a cross sectional, between-subject design. Clinical implications would benefit from a within-subject design; record and track the progress of cognitive abilities associated with concussion management within the subject. Each adolescent develops uniquely; tracking this progress may provide further insight to the development of these processes within the brain. Additionally, future research may question the difference between female and male brain maturation; what role does gender play in recovery of symptoms, assessing and managing concussions in adolescent athletes?

Only specific raw scores were chosen. The ImPACT provides approximately 45 raw scores (composite and subtest scores). All composite scores were chosen for analysis of this study. The subtest scores chosen were because they contribute to the average of composite scores more than other subtest scores. It is reasonable to ask, if the composite scores were significantly different, then why wouldn't the subtest scores be? It is highly encouraged that future studies look at all raw scores reported to be able to pin point exact neuro-communicative skills that are changing from the Young Group to the Older Group.

At this point, it is important to note that during the Third International Conference held in Zurich, of November 2008, McCrory and his colleges did not pin point any major differences in the management of concussion between the adolescent population and adult population. Although recognizing that the adolescent brain and adult brain are different, they state, "The decision to use NP testing is broadly the same as the adult assessment paradigm". They continue to discuss a few differences in terms of management, "timing of testing may differ in order to assist planning in school and home…" McCrory and his colleges recognize brain maturation as an obstacle in concussion management, and offer, "In this age group, it is more important to consider the use of trained neuropsychologists to interpret assessment data…" They also suggest a more conservative return to play approach. These recommendations are helpful, considerate of the delicate adolescent brain; however, adolescents all over the world are playing sports every day, putting themselves at risk of a concussion. It is imperative that we change the current procedure to meet specific standards for specific populations.

4.1 Conclusions

The current study discusses brain maturation and the influence it has on current concussion management. The results of the study suggest that adolescents with self-report of no history of concussion have an improved score on the ImPACT battery across age groups on specific composite scores and subtest scores. During one person's high school experience, his or her baseline performance will change. It is imperative that current concussion management recognizes brain maturation in this specific population. It is recommended that adolescent athletes should have repeat baseline assessment, at minimum twice, throughout their high school experience, once as freshmen and again as juniors. This procedure will help establish a more individualized management plan for adolescent athletes and increase their safety during return to play decisions.

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Appendix A

Mann Whitney – U Results

Retrieved from output analysis of SPSS

	Composite and subtest scores				
	verbal memory composite	visual memory composite	visual motor speed composite	reaction time composite	impulse control composite
Mann-Whitney U	17578.000	19721.500	13725.500	14326.500	19389.500
Wilcoxon W	42554.000	44697.500	38701.500	30797.500	44365.500
Z	-2.232	-.394	-5.531	-5.022	-.681
Asymp. Sig. (2-tailed)	.026	.693	.000	.000	.496

	total symptom score	word memory hits immediate	word memory hits delay	design memory hits immediate	design memory hits delay
Mann-Whitney U	17760.500	19619.000	18413.000	18517.500	19872.500
Wilcoxon W	42736.500	44595.000	43389.000	43493.500	44848.500
Z	-2.093	-.563	-1.560	-1.472	-.271
Asymp. Sig. (2-tailed)	.036	.573	.119	.141	.786

	X's and O's total correct memory	symbol match total correct visible	symbol match total correct hidden	color match total correct	3 letters percent of total letters correct
Mann-Whitney U	20006.500	20042.000	18488.000	19282.000	17679.000
Wilcoxon W	36477.500	36513.000	43464.000	44258.000	42655.000
Z	-.151	-.219	-1.469	-1.065	-2.239
Asymp. Sig. (2-tailed)	.880	.827	.142	.287	.025

Appendix B

Independent Sample t – test

Retrieved from output analysis of SPSS

Independent Samples Test									
		Levene's Test for Equality of Variances		t-test for Equality of Means					
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Cognitive Effciency Index	Equal variances assumed	.371	.543	-2.846	402	.005	-.03653	.01283
	Equal variances not assumed			-2.857	390.037	.005	-.03653	.01279
verbal memory composite	Equal variances assumed	.157	.692	-2.400	402	.017	-2.19917	.91635
	Equal variances not assumed			-2.406	388.455	.017	-2.19917	.91417
visual memory composite	Equal variances assumed	.450	.503	-.584	402	.559	-.71028	1.21556
	Equal variances not assumed			-.582	378.193	.561	-.71028	1.22086
visual motor speed composite	Equal variances assumed	.240	.624	-5.648	402	.000	-3.50700	.62091
	Equal variances not assumed			-5.645	384.271	.000	-3.50700	.62125
reaction time composite	Equal variances assumed	4.089	.044	4.976	402	.000	.03590	.00721

	Equal variances not assumed			5.067	401.547	.000	.03590	.00708
impulse control composite	Equal variances assumed	1.541	.215	.093	402	.926	.04296	.46033
	Equal variances not assumed			.095	401.996	.924	.04296	.45040
total symptom score	Equal variances assumed	2.460	.118	-1.655	402	.099	-1.38877	.83911
	Equal variances not assumed			-1.633	361.706	.103	-1.38877	.85025
word memory hits immediate	Equal variances assumed	.449	.503	-.531	402	.596	-.04192	.07901
	Equal variances not assumed			-.531	386.346	.596	-.04192	.07894
word memory hits delay	Equal variances assumed	.586	.445	-1.450	402	.148	-.21376	.14745
	Equal variances not assumed			-1.457	391.727	.146	-.21376	.14672
word memory total percent correct	Equal variances assumed	.123	.726	-1.244	402	.214	-.75738	.60889
	Equal variances not assumed			-1.237	376.820	.217	-.75738	.61204
design memory hits immediate	Equal variances assumed	.294	.588	-1.376	402	.169	-.18661	.13558
	Equal variances not assumed			-1.381	389.770	.168	-.18661	.13513
design memory hits delay	Equal variances assumed	.018	.895	-.382	402	.703	-.05716	.14973
	Equal variances not assumed			-.383	389.920	.702	-.05716	.14921

design memory total percent correct	Equal variances assumed	.043	.835	-1.106	402	.269	-1.21653	1.10004
	Equal variances not assumed			-1.106	384.612	.270	-1.21653	1.10039
X's and O's total correct memory	Equal variances assumed	.987	.321	-.038	402	.970	-.00897	.23510
	Equal variances not assumed			-.038	381.299	.970	-.00897	.23568
symbol match total correct visible	Equal variances assumed	.099	.753	-.110	402	.913	-.00401	.03660
	Equal variances not assumed			-.111	397.713	.912	-.00401	.03620
symbol match total correct hidden	Equal variances assumed	1.187	.277	-1.563	402	.119	-.29344	.18777
	Equal variances not assumed			-1.575	394.758	.116	-.29344	.18633
color match total correct	Equal variances assumed	10.139	.002	-1.822	402	.069	-.24178	.13269
	Equal variances not assumed			-1.910	376.129	.057	-.24178	.12658
color match average correct reaction time	Equal variances assumed	4.472	.035	2.151	402	.032	.03445	.01602
	Equal variances not assumed			2.223	396.421	.027	.03445	.01549

3 letters percent of total letters correct	Equal variances assumed	.866	.353	-2.186	402	.029	-2.59176	1.18546
	Equal variances not assumed			-2.207	396.363	.028	-2.59176	1.17440

Vita

Jacqueline Picone was born in Franklin Square, New York where she spent her childhood. She attended high school at Valley Stream North High School, located in Franklin Square and graduated with honors. She furthered her education at Mount Saint Mary College located in Newburgh, New York. There, Jacqueline received a Bachelors of Arts in Psychology. Following graduation, Jacqueline was married to Michael Picone, currently a Captain in the United States Army, who was required to relocate to Fort Bliss, in El Paso, TX. Jacqueline enrolled in classes at the University of Texas at El Paso in the Speech-Language Pathology Department. She was later accepted into the program for a Masters of Science in Speech-Language Pathology. Jacqueline soon discovered her interest in concussion management and cognitive therapy. She joined Dr. Salvatore's research clinic to gain more knowledge and experience. Currently, she continues to take part of in the research clinic and continue graduate work towards her degree.

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