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INVESTIGATING POST-CONCUSSION NEUROCOGNITIVE DEFICITS USING
THE IMMEDIATE POST-CONCUSSION ASSESSMENT AND COGNITIVE
TESTING TOOL

BY

MEGAN EKERN

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Nutrition and Exercise Sciences

Specialization in Exercise Science

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2020

THESIS ACCEPTANCE PAGE

Megan Ekern

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree.

Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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This thesis is dedicated to my family; Mom, Dad, Mackenzie, and Miranda, and everyone mentioned in the Acknowledgements. Their positive support, encouragement, and vast amounts of coffee carried me through this process. I would not be where I am now without them.

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ABBREVIATIONS

AT	athletic trainer
GCS	Glasgow Coma Scale
ImPACT	Immediate Post-Concussion Assessment and Cognitive Testing
LOC	loss of consciousness
NP	neuropsychological
SRC	sports-related concussion
TBI	trauma brain injury

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ABSTRACT

INVESTIGATING POST-CONCUSSION NEUROCOGNITIVE DEFICITS USING
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2020

Concussions represent a serious public health concern due to their severe short and long-term consequences. Many adolescents participate in sports that involve the chance of injuries such as concussions. Concussive injuries can be difficult to describe because most symptoms involve non-physical indicators such as impaired cognition, altered behavior, or sleep disturbances. Symptoms can also be influenced by age, gender, and previous history of concussions. Current best practice is to remove the athlete from activity and perform several tests to critically evaluate and assess the injury. ImPACT is a type of neuropsychological testing that includes patient information, baseline tests, post-injury assessments, self-reported symptomology, and history of previous concussions. The objective of this study is to observe prevalence and incidence of concussions in high school student athletes using ImPACT. Composite scores were also compared at baseline, 24-72 hours post injury, and 7 days post injury reported overall and by gender stratification. Prospective cohort study was performed to observe concussion rates in rural adolescent using ImPACT profiles. ImPACT identified 3,224 participants in this study and completed annual baseline testing and self-reported histories of concussions. Concussions described in the present study were recognized by certified athletic trainer who performed follow-up assessments at 24-72 hours post-injury and reassessed at 7 days

post-injury. Baseline data, 24-72-hour post-injury, and 7 days post-injury were compared using repeated measures analysis of variance with post-hoc testing using a Bonferroni adjustment for multiple comparisons. Overall and gender-stratified ImPACT composite scores indicated fluctuations in scores starting at baseline, decreasing at 24-72 hours post, and then rising to just about baseline scores at 7-days post. The prevalence rate of concussions among this population of adolescents was 13% with American football reporting the most concussions. ImPACT composite scores did not vary significantly among genders but there is individual composite score differences. ImPACT can provide a patient history of concussions and track progression of recovery. More research is needed to better understand outcomes and severity of adolescent concussions.

INTRODUCTION

Concussions are a serious public health concern that can have life-long consequences for any individual, especially adolescents.¹ Most adolescents enjoy the ability to compete in sports and recreation related activities; however, participation also presents the risk for a concussive injury also known as a sports-related concussion (SRC). Even within the same individual, each concussion is a unique event with a diverse clinical presentation.² A concussion involves decelerative and accelerative forces applied to the head by a direct hit to the head, neck, or face resulting in temporary neurological impairment and assorted clinical signs and symptoms that may be difficult to detect.² Since concussions occur as a result of these forces, the concussion risk is related to the higher amount of angular acceleration during impact and the which results in a concussion.³ The most commonly described concussive injury symptoms include physical, cognitive, emotional, and sleep disturbances with symptom duration ranging from hours to months.⁴

Concussion vs Traumatic Brain Injury

Sports can cause repetitive trauma to the head and brain, resulting in a traumatic brain injury (TBI); however, not all TBI's are classified as a concussion.⁵ Most concussions fall under the mild TBI classification according to the Glasgow Coma Scale (GCS).⁶ Sport-related concussions are traumatic brain injuries (TBI's) and classified as mild if the individual does not lose consciousness and has a Glasgow coma score of 13-15.⁷

A TBI can be classified by mild, moderate, or severe with serious head injuries resulting in an emergency room visit.⁸ TBI's have historically been underdiagnosed and

misdiagnosed leading to complications with symptoms and prolonged recovery.⁹ Rates of sport and recreation related concussion injuries have increased significantly over the last couple decades and continue to escalate.^{8,10} Appropriate recognition and care provided during the moments after a TBI is sustained significantly impact the likelihood of the individual fully recovering.

Recognition of a Concussion

If a suspected concussion occurs to an individual, they are immediately removed from play and evaluated on the sideline or an appropriate area. Once first aid issues are addressed, a sideline assessment can take place. This assessment includes identification of injury, cognitive functioning evaluation, symptom reporting, balance tests, and cranial nerve functioning.⁴ The medical professional should use multiple diagnostic tools for critical evaluation and proceed with more screening if deemed necessary by substantial head impact or increased symptoms.^{4,11} The individual should not be allowed to return to play or activity on the same day of injury and heavily monitored for the first 24-72 hours post-injury.¹²

Most diagnostic tools involve rating self-reported symptoms, healthcare professionals should be aware and observe common signs and symptoms as well as taking a detailed history.² Evidence recommends medical professionals to utilize multiple tools of assessment to effectively evaluate the potential concussive injury.⁴ Neuropsychological testing (NP) is important for concussion assessment and management because healthcare providers can make evidence-based decisions along with a clinical evaluation for the athlete's return to play and learning.¹³ Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), when used as a NP test

provides neurocognitive data that may help in the assessment of a concussion in high school athletes.¹⁴

Athletic trainers, coaches, and family should be aware of the specific signs and symptoms that should be monitored to determine whether the conditioning is improving in an effort to prevent further injury and guide recovery. The individual should not be left alone after the injury and should be monitored for worsening symptoms.⁴ Red flags for a more severe concussion can include unequal pupil dilation, worsening headache that does not resolve, seizures/convulsions, or continuous vomiting or nausea. If these conditions are observed, immediate medical attention is required.¹⁵ Efficient evaluation of the head injury immediately after impact on the sideline or within 72 hours of injury allows for a greater opportunity for recovery from a concussion.^{11,16}

Pathophysiology of Concussions

Concussions have been shown to affect the immature adolescent's brain to a greater extent than an adult's brain.¹⁷ The adolescent brain is rapidly maturing and adolescents are continuously learning new skills and abilities used in school, sports, and social relationships.¹⁸ A concussion can abruptly disturb brain processes and developments temporarily for adolescents.^{19,20} Concussions can result in neurological disruption causing a metabolic emergency resulting in axonal damage, cell death, and impaired neurotransmission functioning.¹⁹ The majority of these neurologic injuries are believed to heal within 7 to 10 days.^{7,16} The neurometabolic crisis created by a concussion is managed by removing the athlete from play immediately and prescribing

physical and cognitive rest until symptoms resolve.²¹ Most recommendations related to concussion injuries tend to focus on the adult population with little mention of treatment for adolescents. Prior studies have reported differences between the injury processes after concussions with greater severity generally observed in children and adolescents.¹⁹ Due to the complexity of an adolescent concussion, management and care must be tailored to the individualized needs of the patient.

Signs and Symptoms

A myriad of cognitive, physical, emotional, and sleep disturbances may be present following a concussive injury (Table 1).^{2,11,22}

Table 1. Signs and Symptoms of a Concussion²

Physical	Cognitive	Emotional	Sleep
<ul style="list-style-type: none"> - Headache - Nausea/Vomiting - Balance Problems - Visual Problems - Fatigue - Dizziness - Sensitivity to light - Sensitivity to noise - Dazed - Stunned 	<ul style="list-style-type: none"> - Feeling mentally “foggy” - Feeling slowed down - Difficulty concentrating - Forgetful of recent information - Difficulty remembering - Confused about recent events - Answers questions slowly - Repeats questions 	<ul style="list-style-type: none"> -Sadness -Anxiety -More emotional -Nervousness 	<ul style="list-style-type: none"> -Drowsiness - Sleeping more than usual - Sleeping less than usual - Difficulty falling asleep

These symptoms create debilitating consequences affecting the cognitive capacity of adolescent athletes that upset their activities of daily living. For example, difficulty

concentrating on tasks, feeling foggy or slowed down, and troubles remembering recent events are common complaints from athletes following a concussion. Concussions not only cause athletes to be removed from participation, but can also contribute to social isolation and related mood disturbances.²³ These symptoms are not visible to the eye and must be taken seriously in order to properly recover from injury. Adolescents who suffer a concussion typically experience a wide range of signs and symptoms with the most common self-reported symptoms including headaches; dizziness, nausea, confusion, amnesia, and a loss consciousness (LOC).^{2,24}

A LOC does not need to occur to constitute a concussion.^{2,16} Previously, it was widely accepted that LOC indicated a more severe concussion; however, the International Conference on Concussion in Sport determined that only an extended episode of LOC for greater than one minute could influence injury management.^{2,21,25} Studies revealed amnesia, specifically retrograde amnesia was found to create more neurocognitive deficits in athletes.^{25,26}

Epidemiology of Sport Related Concussions

An estimated 1.1-1.9 million SRC's occur every year in adolescent athletes²⁷. Adolescents often play multiple sports and participate in extracurricular and recreational activities along with going to school. A concussion may upset a young individual's normal daily activities; school, sports, work, family, friends, etc.^{2,11,23} According to the high school athletics participation survey, approximately 7.8 million adolescents participate in sports annually and as a greater emphasis is placed on the importance of physical activity, participation continues to rise.²⁸ Current evidence indicates that while

all sports pose a risk of concussion, there are certain sports where that risk is greater.^{29,30} High intensity and direct contact between participants increases the likelihood of a collision or injury and most concussions occur in contact and collision sports such as American football, soccer, basketball, hockey, lacrosse, and rugby.²⁹⁻³³ The most common mechanism of injury for a concussion involves a collision between two participants.^{29,30,32,33} At the high school level, American football represents the sport with the highest incidence of concussion (Table 2).^{30,33,34} A greater proportion of concussions occur during competition than in practice and out of all the sports-related injuries, concussions account for roughly 15% of reported injuries.²⁴

Table 2. Incidence of Concussions in 20 High School Sports³⁴

Number of Concussions				Number of Concussions			
	Competition	Practice	Overall	Competition	Practice	Overall	
Boys only sports				Girls only sports			
American Football	2521	1662	4183	Soccer	864	191	1055
Soccer	421	107	528	Basketball	504	142	646
Wrestling	292	273	565	Volleyball	236	187	423
Lacrosse	256	67	323	Lacrosse	152	57	209
Basketball	224	152	376	Softball	133	92	225
Ice Hockey	187	67	208	Field Hockey	77	22	99
Baseball	96	40	136	Swimming	8	28	36
Track and Field	11	14	25	Track and Field	16	19	35
Swimming	4	14	18	Cross Country	3	5	8
Cross Country	0	4	4	Coed Cheerleading	74	366	440

Gender Differences

American football is the most popular sport among high school males with 1 million athletes and outdoor track and field has the most female participants. Females who participate in soccer are at the greatest risk of a concussion while males are at greatest risk during American football.^{28,30,33,35,36} Also, gender differences are common with the type of symptoms experienced with a concussive injury. Some studies found that females suffer more somatic symptoms and the symptoms last longer than their male counterparts.^{29,37-39} Females tend to feel more discomfort with a concussion and display a different pattern of symptoms than males.^{33,35,37,40,41} Evidence also shows males tend to experience cognitive symptoms like amnesia, confusion, and disorientation while females reported neurobehavioral issues and feeling drowsy.^{24,37,40,42}

Another study looked at the differences in head-neck segment dynamic stabilization that investigated the variations in gender and cited the female's head-neck mass was 43% less than males resulting in the potential for greater angular acceleration for females.⁴³ One study observed the differences in head circumference ratio of male and female high school athletes and found an association between smaller neck to head circumference ratio with a smaller mean in neck strength resulting in a concussion.³ Overall, it appears as though gender differences may exist but may not be consistent. These findings once again highlight the need to treat every concussion as a unique event with a cascade of symptoms that may be unpredictable.

Severity and Outcomes of Sport Related Concussions

Previous studies have reported that symptoms generally persist for seven to ten days, but some athletes continue to experience symptoms over 3 weeks following their

injury.^{44,45} On average, high school athletes also experience a longer recovery time which stresses the importance of critical evaluation when suspecting a concussion.⁴⁵ The American Medical Society specifies concussions with prolonged and increased frequency of symptoms that may indicate an extensive recovery time and return to play protocol for the adolescent patient.¹¹ Athletes who have a previous history of concussions also tend to have an increased chance of re-injury.⁴⁶ High school athletes suffering from a concussion, or more than one, can potentially increase number of symptoms or lengthen recovery time.⁴⁷

Despite the alarming healthcare concerns related to injury, research has tried to describe common concussion risk factors that should be considered for appropriate care and recovery following a concussion. Adolescents display a higher susceptibility and impacted recovery from a concussive injury. Various variables could potentially influence an adolescent's perception and understanding of concussions that may affect how the injury is reported. Continual research on concussions will help provide answers on how to deal with safety issues like increased severity and incidence of concussions, especially in the younger populations who participate in sports. Based on the present information in this review of literature, the following study was performed to investigate the prevalence and incidence of concussions in high school student athletes using annual baseline testing via ImPACT. Overall ImPACT composite scores were reported and observed at baseline, 24-72 hours, and 7-days from post-concussive injury for score variations due to concussive incidents. Also, ImPACT composite scores were compared for the same score variation after concussive incident between genders.

MATERIALS AND METHODS

Data was obtained from a multi-site prospective cohort study investigating the prevalence and outcomes of concussions in local school districts. Student-athletes competing in interscholastic sports in eight rural school districts within a 60-mile radius of South Dakota State University were enrolled in this study. This study was approved by the SDSU Institutional Review Board. Students provided assent and parents provided permission prior to the beginning of testing.

Testing Protocol

Baseline testing was completed prior to the start of the athletic seasons in the seven school districts each year from 2012-2019. Testing sessions were delivered and supervised by licensed athletic trainers. ImPACT is a neuropsychological test that requires a computer with a keyboard, mouse, and internet access. Baseline testing and post injury testing was completed in approximately one hour for the individual. Baseline testing was performed prior to the start of the academic year. Baseline and post-injury evaluations were not completed in the same day. Test administrators explained instructions well, promoted a quiet testing environment, reduced distractions and encouraged the athlete's best effort while testing.

If a participant sustained a concussion, he/she was directly removed from activity/competition and referred to a designated medical provider. This included either the assigned Athletic Trainer (AT) or another medical provider within the area. The student-athlete was assessed as immediately as feasible. If the AT was on site, the student was evaluated immediately post-injury; however, if the AT was not immediately

available, the student-athlete was removed from activity and referred to the AT or physician as soon as possible for evaluation, diagnosis and care. The AT followed a clinically appropriate established protocol for assessment, including self-reported symptomology and neurocognitive assessments. Concussion management was at the discretion of the medical provider. Student-athletes chose the provider they would like to see in all cases. At minimum, concussed student-athletes were assessed at 24-72 hours following injury; however, they could be reassessed in additional sessions pertaining to needs of clinical evaluation as determined by the healthcare provider. Timing of re-assessment is supported by evidence and is consistent with recommendations for children.⁴ Data was also shared with the student-athlete, parent, athletic trainer and other providers as deemed allowable by parent permission/student assent form.

ImPACT® Testing.

ImPACT® is a commonly used computerized test which consist of eight tests that assess the student-athlete's attention, memory, reaction time, and information processing speed. ImPACT® testing begins by asking participants to complete a self-report symptomology questionnaire that allowed students to identify symptoms they are experiencing, and rate identified symptoms on a scale of one to six. The questionnaire includes 22 different symptoms that are commonly reported following a concussive injury^{48,49}. In addition to self-report symptomology, ImPACT contains a variety of neurocognitive evaluations including immediate and delayed word recall, immediate and delayed design recall, a symbol match test, a three-letter recall, the X's and O's test, and color-match test¹⁴. These various tests are commonly referred to as; Verbal Memory,

Visual Memory, Visual Motor, Reaction Time, Impulse Control, and self-reported Total Symptom Score.

A data abstraction was performed with all ImPACT records during the study being abstracted. The dataset was extracted from ImPACT Applications. Using the full dataset, prevalence and incidence was calculated by determining the number of individuals who suffered a concussion as well as the total number of unique observations in the dataset and the number of person-years follow-up. Following calculation of prevalence and incidence, the data were restricted by removing all baseline tests that did not have a post-concussion assessment performed within the year following the baseline test. This resulted in a final data set that included only individuals who suffered a concussion during the study period. This was the dataset used for the investigation of changes in ImPACT composite scores following a concussion.

Data Analysis

Participant characteristics were given as proportions of participants in each category of the demographic and health history variables. Repeated measures analysis of variance was used to determine whether or not changes in composite scores were different among visits. Person years was the denominator in the incidence calculation. Post-hoc comparisons among visits were further evaluated using a Bonferroni adjustment. All analyses were performed using STATA version 15 (*Stata Statistical Software: Release 15*. College Station, TX: StataCorp LLC).

RESULTS

Participant Characteristics

Participant characteristics are shown in Table 2. Baseline tests were performed on 3,224 individuals (1,729 males and 1,495 females). In males and females, the largest proportion of participants came from the 14 to 16-year age group followed by 13 and younger and the smallest proportion from 17 years and older. Fewer than three percent of all participants indicated that they are below average students. A small group of participants reported have a previous diagnosis of ADD or AHDHD, dyslexia, or autism (Table 3).

Table 3. Participant Characteristics

	Females	Males
Number of Participants	1,495	1,729
Age		
<i>13 or younger</i>	31.8%	31.6%
<i>14 to 16</i>	51.6%	48.3%
<i>17 and older</i>	16.6%	21.1%
Student Quality		
<i>Above Average</i>	49.0%	41.0%
<i>Average</i>	49.2%	56.2%
<i>Below Average</i>	1.8%	2.8%
ADD or ADHD Diagnosis (% Yes)	5.0%	9.5%
Dyslexia Diagnosis (% Yes)	1.7%	2.1%
Autism Diagnosis (% Yes)	0.2%	0.7%

Prevalence and Incidence of Concussion

In the present study, the overall prevalence of concussion was 13.1 percent and the incidence rate were 7.3 per 1,000 person years follow-up. The prevalence rate was not significantly different between males and females at 13.9% and 12.3%, respectively.

Similarly, to prevalence rates, the incidence rates did not differ between males (7.9 per 1,000 person-years) and females (6.7 per 1,000 person-years). The largest proportion of concussions occurred in American football (42.2% of all concussions), basketball was second with 21.4% of total concussions, and volleyball was third with 12.1% of all concussions. Cheerleading and wrestling had similar percentages under 10% of concussions. Ice hockey, soccer, track and field, and other accounted for less than 5% of concussions of the population (Table 4).

Table 4. Percentage of Concussions During Participation in Specific Sports

	Percent of all Concussions
American Football	42.2%
Basketball	21.4%
Volleyball	12.1%
Cheerleading	6.9%
Wrestling	5.2%
Ice Hockey	2.9%
Soccer	2.9%
Track and Field	2.9%
Other*	3.5%

*Other includes baseball, golf, gymnastics, cross country

IMPACT Test Scores

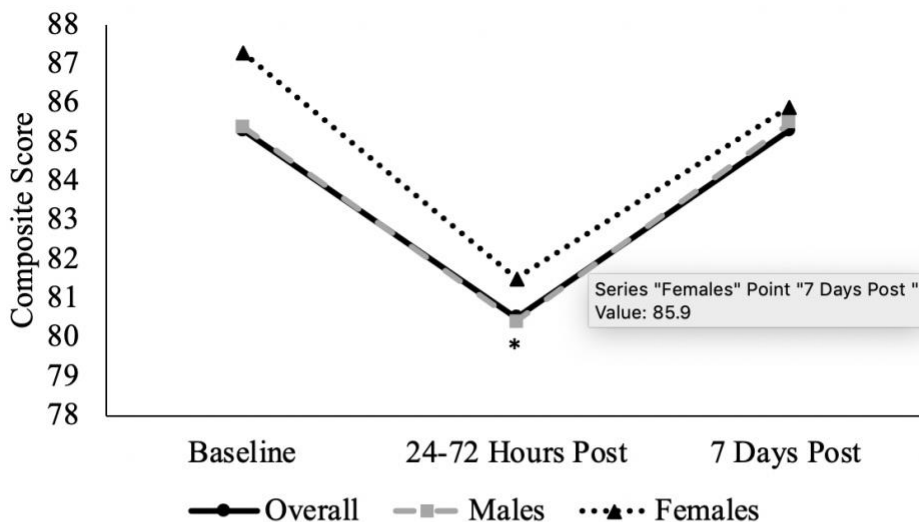
Verbal memory composite score was lower than baseline at 24 to 72 hours following the concussive incident but returned to baseline by 7 days post (Figure 1A). Results were similar when analyses were stratified by gender with males and females both exhibiting a deficit at 24 to 72 hours and returning to baseline by 7 days post (Figure 1A). Visual memory composite was lower than baseline at 24 to 72 hours following the concussive incident (Figure 1B). At 7 days post, scores were lower than baseline but greater than 24 to 72 hours (Figure 1B). Results were similar when analyses were

stratified by gender with males and females both experiencing a deficit at 24 to 72 hours and increasing slightly under baseline at 7 days post (Figure 1B).

Visual motor composite score was lower than baseline at 24 to 72 hours following the concussive incident but increased more than the baseline at 7 days post (Figure 2A). Results were similar when analysis were stratified by gender with females exhibiting a deficit at 24 to 72 hours and doing better than baseline at 7 days post (Figure 2A). Deficits in score were not observed in males at 24 to 72 hours but also showed improvements from baseline at 7 days post (Figure 2A). Reaction time composite was lower than baseline at 24 to 72 hours following the concussive incident but returned to baseline by 7 days post (Figure 2B) Results were similar when analyses were stratified by gender with males and females both experiencing a deficit at 24 to 72 hours and returning to baseline by 7 days post (Figure 2B).

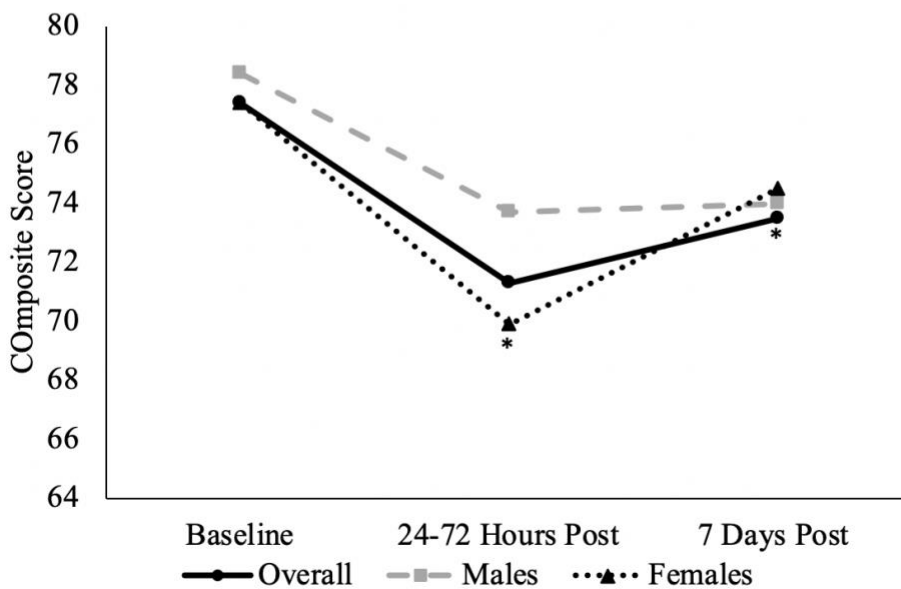
Impulse control composite was lower than baseline at 24 to 72 hours following the concussive incident but returned to baseline by 7 days post (Figure 3A). Results were similar when analyses were stratified by gender with males and females both exhibiting a deficit at 24 to 72 hours and returning to baseline by 7 days post (Figure 3A). Total symptom score was higher than baseline at 24 to 72 hours following the concussive incident but returned to baseline by 7 days post (Figure 3B). Results were similar when analyses were stratified by gender with males and females both scoring higher in symptomology at 24 to 72 hours and returning to baseline by 7 days post (Figure 3B).

Figure 1A. Changes in Verbal Memory Composite Overall and by Gender



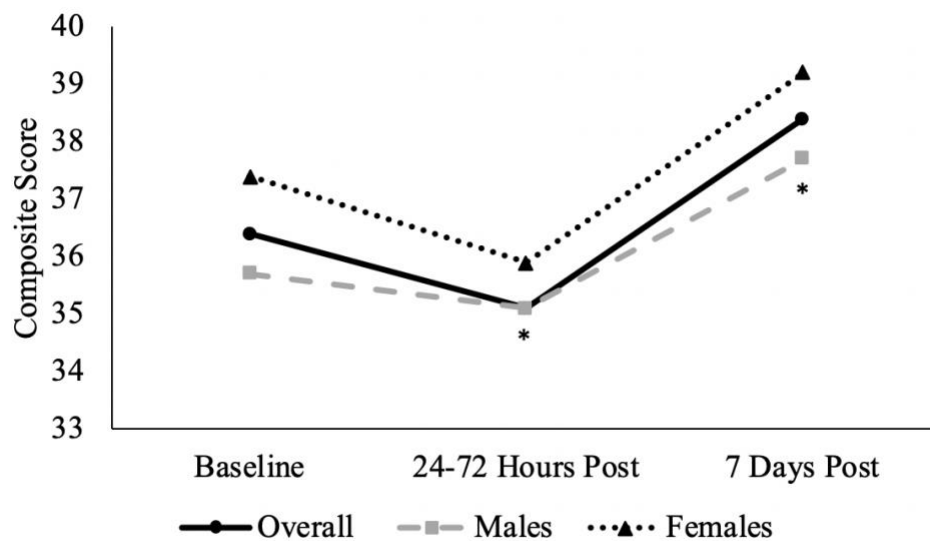
*Denotes a difference from baseline at $p < 0.05$

Figure 1B. Changes in Memory Composite Overall and by Gender



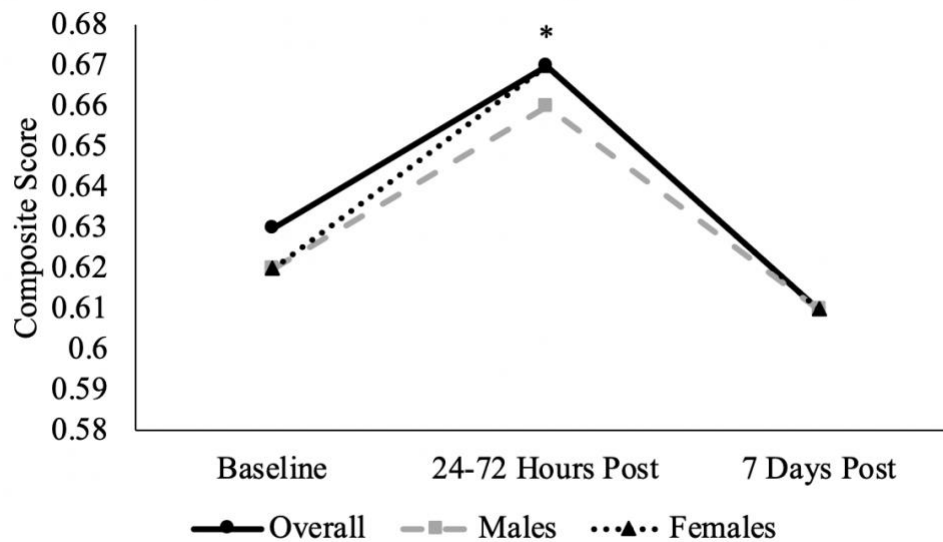
*Denotes a difference from baseline at $p < 0.05$

Figure 2A. Changes in Visual Motor Composite Overall and by Gender



*Denotes a difference from baseline at $p < 0.05$

Figure 2B. Changes in Reaction Time Composite Overall and by Gender



*Denotes a difference from baseline at $p < 0.05$

Figure 3A. Changes in Impulse Control Composite Overall and by Gender

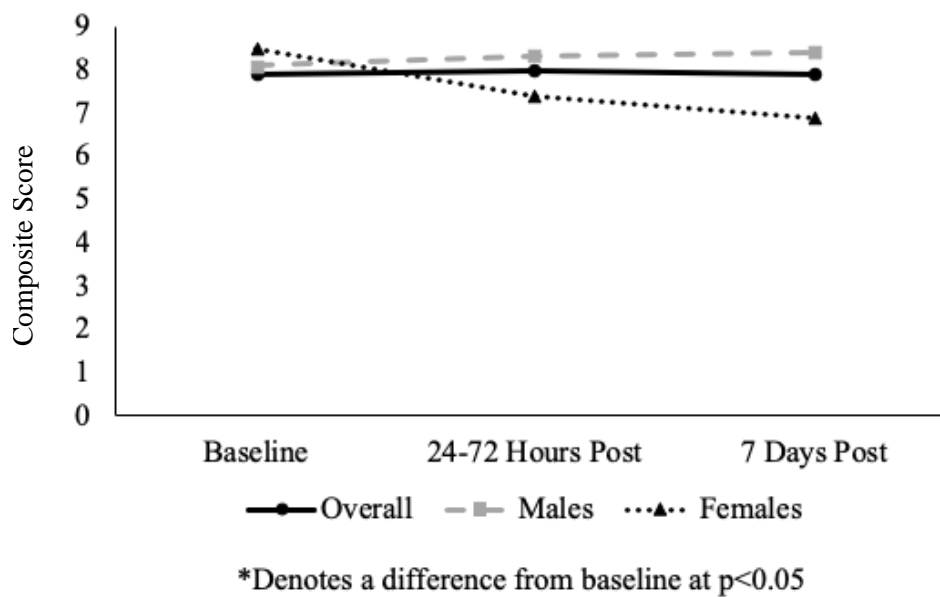
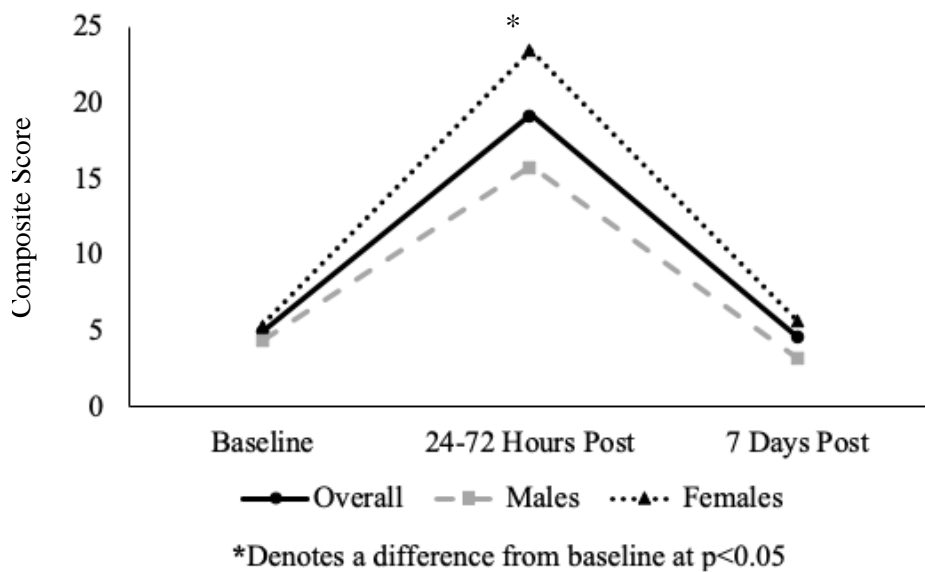


Figure 3B. Changes in Total Symptom Score Overall and by Gender



DISCUSSION

The objective of the study observed ImPACT scores and tracked concussion rates over the course of eight years. Over 13% of participants in the present study suffered a concussion while participating in athletics. This is similar to prevalence estimates by the Centers for Disease Control, but higher rates have been reported in other studies.^{24,29,33,50} Also, in this study, the largest percentage of concussions occurred during American football and this finding is in agreement with previous studies.^{29,37} The prevalence observed in the present study compared with previous work could be related to the student athletes', parents', and coaches' understanding that improved recognition of concussion signs and symptoms. Awareness regarding the danger of repeated concussions has improved in athletes, coaches, administrators, parents, and healthcare providers and as a result, screening has increased and the diagnostic criteria for a concussion has been expanded.²¹ While there are currently minimal methods available for primary prevention of concussions, appropriate recognition and management of concussions can have a beneficial impact on long-term outcomes and serve a secondary preventative role in mitigating the extent of impairments.⁴ Concussion education is critical to everyone involved in athletics and a previous study reported that concussion education may help athletes be mindful of concussive signs and resulted in a higher likelihood of reporting their injury to coaches and medical staff.⁵¹ Concussion education can be provided from medical professionals to coaches and parents before the start of the athletic season with informative meetings and handouts that properly explain the common signs and symptoms of a concussion.

In the present study, the majority of deficits observed at 24-72 hours following the concussive event were no longer present at 7 days post-injury. This is in line with prior studies reporting that symptoms generally resolve between seven and ten days in high school athletes.^{44,45,52}

Overall verbal memory composite scores were found to be lower than baseline 24 to 72 hours after a concussion and returned to baseline at 7 days post with similar results being observed in both genders. The absence of gender differences in our study is in agreement with a prior study that found no significant differences in verbal memory scores between males and females.⁵³ However, this also differed from other studies that have reported marginally higher verbal memory in females than males.^{52,54-56} It is important to consider that the present study investigated change in verbal memory score and therefore any gender differences at baseline would not affect change. Consequently, the similar findings in males and females indicate that the instrument is effective in tracking verbal memory changes in both genders.

Overall visual memory composite scores were lower at 24 to 72 hours after a concussion and increased at 7 days post but still varied from baseline scores. Both genders displayed similar results in visual memory composite. Prior studies using ImPACT found that visual memory composite scores do not vary among male and female athletes at baseline.^{53,54} Other research has been inconclusive with female athletes performing better on visual memory⁵² with other studies reporting that females performed worse than males.^{40,57} These inconsistent findings accentuate the need for baseline testing scores as normative values for the visual motor composite are unlikely to be valuable in diagnosing a concussion. Concussion assessment does not rely on just one ImPACT

composite score so neurocognitive diagnostic data from other concussive assessments should be considered when suspecting a concussion. However, the consistency of the findings in the present study indicate that in the event where baseline testing has taken place, serial assessment following a suspected concussion has great value.

Reaction time composite was lower than baseline at 24 to 72 hours following the concussive incident but returned to baseline by 7 days post with similar results being observed between genders. Prior studies looking at baseline values for reaction time found no gender differences in reaction times^{53,54}, while two other studies reported females performing on better on their Reaction Time scores.^{52,56} Similar to our findings from verbal and visual memory, the results from the present study highlight the need for baselines to be established for every athlete prior to entering competition.

Overall visual motor composite scores were lower than baseline at 24 to 72 hours following the concussion but was significantly greater than baseline at 7 days post injury. Result in composite scores were slightly different by gender with females showing a deficit in visual motor at 24 to 72 hours and males displaying no deficit at 24-72 hours post injury. These findings may indicate a learning effect. If this test was reliable, we would expect that results would never be significantly greater than baseline. If a learning effect is present, then the results of visual motor testing must be interpreted with caution and only used to rule in a concussion and not to rule one out. This is supported by a prior study that reported improvements in visual motor speed over time among college students.⁵⁸

Impulse control composite score was reported lower than baseline at 24 to 72 hours following the concussive incident but returned to baseline by 7 days post. Results

were similar when analyses were stratified by gender with males and females both exhibiting a deficit at 24 to 72 hours and returning to baseline by 7 days post. Other studies did not include impulse control composite scores within their tables and therefore comparisons with prior studies was difficult.⁵²⁻⁵⁵ Further research is necessary to determine if our findings can be replicated; however, at the present time, impulse control appears to be a valuable tool in the serial assessment and management of concussions.

Self-report symptomology represents the most traditional examination used in the diagnosis and management of concussions. In the present study, most individual's total symptom score was higher than baseline at 24 to 72 hours following the concussive incident but returned to baseline by 7 days post. Most results were similar when analyses were stratified by gender with males and females both exhibiting many symptoms at 24 to 72 hours and returning to baseline by 7 days post. These results are similar to other studies finding of no significance difference in the magnitude of the change in symptom scores between genders.^{52-54,57} If participant's symptoms and scores did not resolve within the 7 days, they were referred to a physician for further care. However, in other studies higher post-concussive symptom scores have been reported in females than males.^{55,56} Furthermore, a recent evaluation of symptomology scores indicated that self-report symptoms were not higher in females than males, but the type of symptoms reported were different between genders.⁵⁹

The finding of similar symptom resolution was observed in males and females with most symptoms resolving within 7 days was in agreement with previous studies.⁵² Many of the newest developments in the diagnosis and management of concussions have aimed to use objective measurements as a means of standardizing diagnosis. However,

based on our findings and the findings of previous studies, self-report symptomology remains a vital component in the assessment and management of concussions. This is supported by the consensus statement from the International Consensus Conference on Concussion in Sport and its inclusion in the 5th edition of the Sport Concussion Assessment Tool (SCAT 5).^{4,60}

Most concussions are diagnosed through self-reported symptoms in a subjective manner by athletes; however, a true concussion diagnosis can be complex since players can mask or underreport their symptoms.⁶¹ Current evaluation tools use various grading scales to assess the likelihood that a concussion has occurred. If the athlete does not respond to the questions honestly due to their desire to continue participating, serious consequences including brain damage, permanent disability, or death could result.²³ In high school athletes, much of the pressure to withhold symptoms could be related to pressure from coaches, peers, and parents to play through pain and not miss any time. This is where the importance of developing objective measures to use in concussion diagnoses is critical.⁶² Others may argue that education is the most critical component, however, adolescents often lack an understanding of the severity and consequences of brain injuries which leads to few symptoms reported.^{23,63} McCrea et al found athletes understood potential signs and symptoms of a concussion but did not report the indications to a medical professional about half the time.^{61,62,64} Again, this represents the need for objective tests in cases where self-report symptoms may be intentionally or unintentionally underreported.

Especially in a rural environment, student athletes may benefit using ImPACT as a diagnostic tool for concussive events and track the recovery process because symptom

reporting is subjective among individuals. ImPACT includes symptom recording at the beginning of the computerized test and can involve a post-test symptom reporting to observe if the test caused more symptoms or increased severity. ImPACT is not the only diagnostic means for concussions but does represent a standardized test healthcare professional can utilize for the diagnosis of concussions. ImPACT provides a patient history of concussions and allows medical providers to track the recovery process by observing symptoms and composite scores. The current best practices advise healthcare providers to use multiple diagnostic tools and clinical assessments to best manage adolescent sports-related concussions.⁶⁵

Clinical Recommendation

Concussive injury management involves serious understanding of the individual and be tailored to their specific needs. Evidence shows prescribed forms of physical and cognitive rest within the first 24-72 hours of injury has shown to benefit the individual.⁴ As symptoms resolve and the individual wants to return to sports-participation, medical professionals, like an AT can begin the return to play protocol. The return to play protocol involves a stepwise graded activity specifically aimed slowly reintroduce their sport activity and gauge the individual's response (Table 5).⁴ If symptoms flare up during activity, stop the exercise and rest for 24 hours before resuming the same exercise before progressing to the next step. Each step should be performed with 24 hours in between to not overwhelm the individual.

Modifications and accommodations for work and school can be arranged if symptoms persist and create more issues during recovery. If symptoms do not resolve or

get better after 7-10 days, the individual should be referred to a physician or concussion specialist that can treat post-concussion syndrome.

Table 5. Graded Return to Play⁴

Stage	Activity
1	Symptom limited activity
2	Light aerobic exercise
3	Sport-specific exercise
4	Non-contact training drill
5	Full contact practice
6	Return to sport

Limitations

One limitation to this study includes the incidence rate because participants were not at risk for a concussion for the entire year, nor did they have concussion-based care year around. This may have resulted in the incidence rate being slightly lower than the actual incidence rate. Concussion related care was provided during the months when school was in session, which is usually nine months. These nine months include the common sport seasons where participants are most at risk for a concussion. However, if a participant experienced a concussion during non-school months, they were referred to their family physician and no follow-up was performed.

ImPACT tracks all baseline tests performed for the student athlete, valid and invalid. An invalid test could be an incomplete test or the individual randomly clicked answers throughout the test. Most test administrators tracked invalid baseline tests and tried to retest the individual when this occurred. All baseline tests and post-injury were considered in this study and that may have influenced the prevalence and incidence rates of concussions.

When looking at the visual motor composite score in ImPACT, scores at 7-days post injury were greater than baseline scores meaning a potential learning effect present. Additionally, if a learning effect is determined to be present then we must question whether or not visual motor testing should be done following concussions. ImPACT does not allow for specific test composite modifications within the programing. If the test does not add diagnostic value, then continuing to perform it places undue burden on an injured athlete during a time in which they should be engaging in cognitive rest. Future ImPACT programs could be modified to include tests that accurately test the visual motor aspects related to concussion injuries. Based on the findings in the current study and prior studies, clinicians who choose to utilize the ImPACT program for concussion management should place greater emphasis on verbal and visual memory components than the visual motor component.

Each school had their own testing environment also which can affect results. ImPACT is a computerized test and should be performed in an optimal testing environment under a healthcare provider's supervision. To minimize these distractions: sit athletes comfortably spaced (so they do not race each other); if possible, utilize a quiet room and remove external noises; clean and operative computers with a keyboard and mouse; present test administer for the whole duration of testing; and provide clear and concise instructions for the test.^{11,66}

CONCLUSION

Concussion evaluation is a multifaceted approach that needs more standardized objective diagnostic criteria to make decisions regarding identification of injury and return to play status. The results of this study indicate that the ImPACT testing program is valuable in filling the need for objective testing and its use should continue. ImPACT may offer a valuable insight into the decision making for concussion diagnosis and tracking the neurocognitive effects associated with the injury. ImPACT should be performed under the discretion of a medical professional and consider the total symptom score along with most of the composite scores. Continued study regarding the most critical components of the tool should be utilized to ensure that patient burden is minimized.

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