EFFECTS OF CONCUSSION HISTORY ON NEUROCOGNITIVE PERFORMANCE IN HIGH SCHOOL AND COLLEGIATE ATHLETES AFTER AN ATHLETIC SEASON

By

Aaron M. Sinnott

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Committee Membership

Dr. Justus Ortega, Committee Chair

Dr. Mike Paddack, Committee Member

Beth Larson, Committee Member

Dr. Rock Braithwaite, Committee Member, Graduate Coordinator

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Abstract

EFFECTS OF CONCUSSION HISTORY ON NEUROCOGNITIVE PERFORMANCE IN HIGH SCHOOL AND COLLEGIATE ATHLETES AFTER AN ATHLETIC SEASON

Aaron M. Sinnott

Potential long term neurocognitive (NC) and psychological effects from exposure to concussive and subconcussive forces are of growing international concern. Athletes with a history of prior concussions exhibit lower objective performances and higher symptom reporting when compared to those with fewer injuries. Due to this observation, researchers have hypothesized a dose-response relationship between concussion history and decrements in NC function. For this study, we hypothesized an association between a history of multiple concussions and NC deficits in current soccer and football participants. Those with three or more concussions were predicted to perform worse than those with no prior injuries before an athletic season and experience NC decrements after a season. Athletes (n=101) from 5 high schools and one NCAA Division II university in Humboldt and Del Norte Counties were administered a computerized neurocognitive test with related demographics (ImPACT) and asked to self-report symptoms (PCSS) immediately before and after a competitive athletic season, and were administered an additional survey related to concussion history postseason. A FOUR (concussion history-0, 1, 2, 3 or more) X TWO (time- preseason, postseason) MANOVA was used to analyze ImPACT composite and PCSS scores between the concussion groups and between preseason vs. postseason. Athletes with three or more concussions (n=13) did not obtain
lower preseason (baseline) scores than athletes without a history of concussion (n=53) and there were no significant changes from preseason to postseason composite scores across any concussion group. While findings from this study did not show significant changes in NC scores after a single competitive soccer or football season, there were observed trends that shed light on the importance of comprehensive large scale longitudinal studies.
Acknowledgments

Dr. Ortega- Little did I know, but several years back our first conversation together was so influential on my life here at Humboldt State. I was exceptionally nervous at my lack of preparedness for our first meeting and was welcomed by your eccentric grin as you guided me through the research process. Unbeknown at the time we began a journey which guided me to where I am today. Your insight to solve any problem with a proactive attitude is a combination valuable for any leader. Thank you for offering me the golden opportunity to follow along for the ride.

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Introduction

Concussion, a type of mild traumatic brain injury (mTBI), is a neurological injury experienced when the brain is exposed to rapid accelerations or decelerations (Barkhoudarian, Hovda, & Giza, 2011; Meaney & Smith, 2011). Forces applied to the brain cause neuron axonal damage, resulting in temporary functional impairment (Barkhoudarian et al., 2011). Each year in the U.S. 1.4 to 3.8 million people sustain a concussion while participating in athletic or recreational activities (Langlois, Rutland-Brown, & Wald, 2006). Residual effects of mTBI in former professional athletes have contributed to an increased public awareness of sport related concussions in recent years. In response, appropriate concussion management has become a priority for sports medicine clinicians. Thorough evaluation, immediate care, and follow up treatments are emphasized to promote optimal short and long-term recovery of concussed patients.

Researchers have hypothesized a dose-response relationship between concussion history and decrements in neurocognitive function (Collins et al., 1999; Collins et al., 2002; Covassin, Elbin, Kontos, & Larson, 2010; Guskiewicz et al., 2003). Individuals exposed to concussive forces may exhibit a decreased tolerance to similar biomechanical events over time. In short, someone with a prior concussion or history of multiple concussions would potentially experience greater deficits after encountering similar concussive forces than someone without a previous history of concussion. However, a relationship between concussion history and neurological performance was not observed.
by others (Miller, Adamson, Pink, & Sweet, 2007). These conflicting results necessitate further research investigating the dose-response hypothesis.

**Concussion Background**

Concussion is a neurological injury that results in temporary somatic, and cognitive symptoms, psychological impairments and sleep disturbances that will spontaneously resolve in the majority of cases (McCrory et al., 2013). Direct or indirect biomechanical forces applied to the head induce disturbances to the axons of neurons, initiating a neurometabolic cascade (Barkhoudarian et al., 2011; Len & Neary, 2011). Though not intended as a comprehensive description of concussion injury, the current study requires a simple understanding of the neurometabolic cascade. After axonal stretching, a disruption of ion channels within the cell membrane ensues. Sodium and potassium ion balance is compromised and neurotransmitters are released in an atypical fashion, affecting normal neuron metabolism and function. In an attempt to restore ion homeostasis, adenosine triphosphate (ATP)-regulated pumps along the neuron are activated to restore sodium and potassium levels to proper balance. The need to utilize these ATP-dependent pumps results in hyperglycolysis. Increased cellular metabolism combined with a concomitant decreased cerebral blood flow post injury results in lactate accumulation (Giza & Hovda, 2014). Until appropriate ion balance is reestablished, the brain is considered to be in a “compromised” state whereby additional agitation or impacts can potentially cause severe and even life-threatening conditions (Wetjen, Pichelmann, & Atkinson, 2010).
Due to the complex and microscopic biological mechanisms involved in concussive injuries, is it difficult to diagnose concussion via standard medical imaging. Standard Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) do not show remarkable findings to aid in the diagnosis of concussion. Concussion results primarily in metabolic dysfunction as opposed to structural damage that would be captured using these traditional imaging techniques. Diffuse Tensor Imaging (DTI) and Functional MRI (fMRI) evaluations gained interest from researchers as potentially liable options to detect alterations in neurophysiology (Davenport et al., 2014). But the high cost and scarce availability for fMRI and DTI make it an impractical approach to evaluate possible mTBIs across large populations. For these reasons, medical diagnosis is determined predominantly by observed signs and reported symptoms of the patient.

A concussion can affect several aspects of brain function, which can cause a variety of signs and symptoms from several domains. The domains used to categorize the symptoms are also referred to as symptom clusters. Symptoms commonly reported include, but are not limited to: somatic (headache, dizziness, low energy, light and noise sensitivity), cognitive (memory and attention difficulty), psychological (anxiety, depression) and sleep disturbances (Echemendia, 2012). Assessment of these symptoms is utilized in post-concussion analysis and return to play (RTP) procedures used by sports medicine clinicians (Putukian, 2011). The universal Post-Concussion Symptom Scale (PCSS) is a commonly used survey to evaluate the initial symptoms and observe symptomatic recovery after a concussive injury. Patients self-report symptoms using a
Likert-type scale to grade each symptom on a 0 to 6 range (0 being not present, and 6 being severe). The PCSS is a valid clinical assessment, thereby higher symptom scores are associated with neurocognitive function decrements and neuroimaging abnormalities (Chen, Johnston, Collie, McCrory, & Ptito, 2007). Researchers investigating the PCSS have supported the use of this scale in the proper management of concussion injuries (Dziemianowicz et al., 2012; Guskiewicz & Broglio, 2011; Lovell, 2009).

Neuropsychological Testing

Neuropsychological testing is a fundamental element of proper concussion management. International position statements include neuropsychological testing as a vital component within the appropriate RTP guidelines (McCrory et al., 2013). The advent of computerized neurocognitive tests address several limitations once attributed to traditional pen and paper evaluations. Subtle changes in motor processing speed and reaction time can be determined through computerized programs which would otherwise be too difficult to calculate in pen and paper tests. Selected computerized tests are utilized to assess baseline performances at the start of an athletic season, prior to any head injury. Under conditions when a concussion is suspected, the individual completes the neurocognitive exam again and outcome measures are compared to their baseline scores. Post-injury scores significantly outside reliable change indices based on baseline scores indicate a possible concussion and require further evaluation. Neurocognitive tests are not to be used as a sole diagnostic tool for concussions but when used and interpreted
appropriately, results from neurocognitive tests can serve as a valuable tool for concussion management.

An established measure to evaluate neurocognitive function following mTBI is the Immediate Post Concussion and Cognitive Testing (ImPACT) tool (ImPACT Applications Inc., Pittsburgh, Pennsylvania). This computerized test is a valid measure of neurocognitive function of those suffering from concussive injuries (Schatz & Sandel, 2013). Furthermore, evidence supports the use of ImPACT to detect neurocognitive impairments even in those no longer exhibiting symptoms from an acute head injury (S. P. Broglio, Macciocchi, & Ferrara, 2007).

The ImPACT test is composed of three main sections: a demographics portion, the PCSS, and a neurocognitive test (Dziemianowicz et al., 2012). The demographic background includes patient profile information, pertinent medical history, and prior concussion history. Following the demographics, the PCSS is administered and results are grouped into their distinct symptom clusters for further analysis. The neurocognitive testing procedure is grouped into six modules which include: Word Discrimination, Design Memory, X’s and O’s, Symbol Matching, Color Match, and 3-Letter Memory. Scores from the six modules are used for program calculations to provide four composite scores including verbal memory, visual memory, processing speed, and reaction time. The composite scores are analyzed and compared to baseline data or to normative values for each individual. Differing results in one or combined outcome measures between
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Examinations reflect a decline in neurocognitive function. (Echemendia et al., 2013; Iverson, Lovell, & Collins, 2003). Results from the neurocognitive examination should be incorporated with additional outcome measures such as balance,

ImPACT is a preferred sport concussion assessment tool that addresses shortfalls of pen and paper neuropsychological tests. Computerized tests can be implemented in groups/teams instead of individual appointments. Outcomes such as motor speed and reaction time are collected within the program. In addition, ImPACT includes software intended to vary the test in a randomized fashion to negate practice effects commonly seen in other neuropsychological testing (Dziemianowicz et al., 2012).

Dose-Response Relationship

Based on recent findings of neurologic dysfunction after career-length exposure to mTBIs (Daneshvar et al., 2011), considerable efforts have been made to investigate a dose-response relationship to head injuries. Are those that experience more head injuries at risk for long-term deficits in neurocognitive function? Evidence suggests retired professional boxers are more likely than non-boxers to develop neurological dysfunction and long term cognitive impairment (Rabadi & Jordan, 2001). Boxers exposed to repetitive head injuries over the course of their career increased their risk for developing neuro-degenerative diseases (Daneshvar et al., 2011). Similar observations have been reported in several retired American football players (Gavett, Stern, & McKee, 2011).
These results, among others, have questioned whether executive function is compromised after long term exposure to head impacts during sports participation. Currently, diagnosis of neurodegenerative diseases is made postmortem, leaving little promise for early detection. Medical professionals and researchers alike are investigating the possible predispositions and specific etiology of later life neurocognitive impairments. Answers to these uncertainties may contribute the necessary information to provide prevention strategies before neurodegenerative onset.

One focal area of research has examined the overall number of concussions athletes experience to determine a dose-response relationship to mTBI. Investigators have examined neurocognitive function comparing individuals with and without a history of concussions and confirmed the possibility of a dose-response relationship to concussion injuries (Collins et al., 1999; Collins et al., 2002; Covassin et al., 2010; Guskiewicz et al., 2003). However, observations indicating this relationship are derived from cross-sectional designs. Longitudinal studies are needed to provide evidence that concussive and even subconcussive impacts are responsible for dose-response observations.

Evidence of significant differences in neurocognitive performance indicating a dose-response relationship to mTBI have resulted from cross sectional designs that only examined preseason test results. Collins et al., (2002) compared baseline ImPACT testing across several male and female high school sports and observed the post injury responses
of those who experienced a concussion during their athletic season. Comparisons between groups indicated that athletes who experienced a history of three or more concussions had a higher likelihood of exhibiting multiple “evaluation markers”. These markers were designated as clinical indicators for predicting concussion severity.

Intergroup comparisons indicated a potential dose-response relationship between concussion history and acute responses to subsequent injuries (2002). Unfortunately, the investigators were not able to determine severity or force of concussion impact prior to injury. Varying amplitudes and impact location can affect the acute responses to injury (Broglio, Sosnoff, Shin, et al., 2009).

Brooks et al. (2013) investigated possible lingering effects from previous concussions in adolescent hockey athletes using the ImPACT program. Athletes, from 44 hockey teams including those with and without previous history of concussion, completed baseline neurocognitive testing. There was no relationship between concussion history and neurocognitive performance across all ImPACT composite scores. However, there were differences in subjective symptoms, with greater symptom reporting in previously concussed athletes compared to those with no concussion history. A possible limitation for Brooks et al. (2013) was the age range of the population examined. Participants ranged between 13 and 17 years of age, with a mean age of 15. Possible deficits in neurocognitive function from prior concussion events may not have taken place within this younger age range. Elite adolescent hockey players from upper divisions were incorporated, but no statistical data for years of participation was provided.
Furthermore, sex differences as seen in similar baseline measurements observed by Covassin et al. (2010) were not taken into account.

Several studies have conducted longitudinal observations throughout the duration of a competitive season. Gysland et al. (2012) administered a pre-season and post-season neuropsychological testing battery across forty-six collegiate football players. Athletes completed the Automated Neuropsychological Assessment Metric (ANAM), and Standardized Assessment of Concussion (SAC) tests in addition to the BESS (Balance Error Scoring System) test prior to and after completion of the football season. Postseason comparisons across SAC scores and all domains of the ANAM test yielded no significant differences among those who self-reported at least one prior concussion. This finding conflicts with neurocognitive deficits found, specifically reaction time, for the ImPACT test by a similar study (McAllister et al., 2012). Head and body impacts incurred throughout the duration of a season were recorded in both of these studies utilizing the Head Impact Telemetry (HIT) system. Yet, average impacts per player experienced during a season differ considerably. McAllister et al. (2012) combined both hockey and football into one “contact sport” group for analysis. Gameplay and head impact exposure risk vary across these two sports, possibly misrepresenting the “contact” group. Nonetheless, the aforementioned study assessed neurocognitive function through the ImPACT test while Gysland et al. (2012) used the ANAM. Though the ANAM has sufficient retest reliability (Segalowitz et al., 2007), comparisons between examinations remain an area of needed research. Furthermore, both studies categorized individuals
with a concussion history and with no concussion history into separate groups. Prior findings suggest neurocognitive changes are observed after experiencing two or more concussions (Covassin et al., 2010). Those with a history of one concussion may have masked potential deficits from the remaining members of the “concussion history” group. Concussion history differences within the same group may have contributed to their contrasting conclusions.

Recently, it has been shown that high school football players not diagnosed with a concussion exhibit alterations in brain physiology and neurocognitive performance during an athletic season (Talavage et al., 2013). These results indicate the potentially negative influence of subconcussive impacts on brain function over the course of a football season. Forces applied to the brain below the threshold to cause concussion-like symptoms are considered as subconcussive forces (Dashnaw, Petraglia, & Bailes, 2012). This is the first evidence demonstrating neurophysiological changes in high school football players after completing a full season without a diagnosed concussion. Contradicting results from a previous report did not show neurocognitive performance differences following a full collegiate football season (Miller et al., 2007). However, Talavage et al. (2013) also measured differences in neurophysiology via functional Magnetic Resonance Imaging (fMRI) technique. Functional MRI has emerged as a promising method for assessing presence of and recovery from concussion episodes (Kutcher et al., 2013). The present study by Talavage et al. (2013) was limited by the small sample size (21 players) and generalizable only to high school football players.
Furthermore, no comparisons between concussion history and neurocognitive outcomes were assessed.

The purpose of the present study was to observe neurocognitive function in contact sport athletes exposed to head impacts. It was hypothesized that multiple concussions would be associated with ongoing deficits in neurocognitive function. For this study, two outcomes were predicted: 1) Athletes who self-report three or more concussions will obtain lower scores on a neurocognitive assessment (ImPACT) than athletes who self-report no history of concussion injury for a baseline examination. In addition, 2) Athletes with three or more concussions will score lower on a neurocognitive test (ImPACT) after participating in an athletic season without experiencing a concussion as compared to baseline.
Methods

Design

This study utilized a prospective repeated measures design encompassing one complete athletic or competitive season. Athletes from selected high school and collegiate contact sports performed baseline concussion testing using the ImPACT software prior to the athletic season. A follow-up examination was conducted at the season’s conclusion. Postseason testing was composed of the ImPACT test and an additional head impact survey designed to examine player exposure to head impacts over the course of the season. Subjects were grouped based on the number of self-reported concussions identified at the postseason evaluation.

Participants

Participants included male and female competitive athletes from Humboldt State University (HSU) and selected high schools. HSU athletes participating in men’s soccer, women’s soccer, and football were eligible to participate. High school interscholastic football and male and female soccer athletes were also be included. All participants lived in Humboldt and Del Norte Counties.

Participants were excluded from postseason statistical analysis if a concussion was clinically diagnosed within six months prior to the study or during the competitive season. Exclusion criteria also included a previously diagnosed psychiatric disorder or
learning disability. In addition, those who have received treatment or counsel for illegal substance abuse were not included in data analysis for this study. Exclusion criteria were based on self-report responses obtained from the preseason and postseason surveys.

Groups

Four independent groups were created based on the number of prior concussions and determined from a self-reported history at the postseason survey. Participants indicated the number of concussions in a personal history obtained at the conclusion of the season. Participants were assigned to a zero concussion group, one, two, or a three or more concussion group.

Measures

Neurocognitive performance outcomes were measured through the online version of the Immediate Post-concussion Assessment and Cognitive Test (ImPACT). ImPACT is a computerized neurocognitive test validated in assessing the acute effects of mTBI (Schatz & Sandel, 2013). The complete exam includes three separate sections: demographics, symptom checklist, and a neurocognitive test battery. The demographic portion obtained the individual’s personal information and education background. In addition, several questions specific to concussion history are also incorporated within this section. The ImPACT program also incorporates the Post-Concussion Symptom Scale (PCSS); a questionnaire commonly used to manage mTBI. The neurocognitive exam
assesses attention, memory, and processing speed through six distinct modules. Results from all six modules are computed within the software to produce four outcome measures or composite scores—visual memory, verbal memory, processing speed, and reaction time. Higher scores for visual memory, verbal memory, and processing speed reflect superior performances. Conversely, a lower score for the reaction time composite indicates a better result (ImPACT, 2010).

An additional outcome measure tracked by ImPACT is the impulse control. This reflects the number of instances where an individual performs an omission or commission error during reaction tests. A high impulse control score can be attributed to a false interpretation of the instructions or a deliberate attempt to perform poorly. Intentionally performing worse on baseline examinations to provide a low score for future comparisons is referred as “sandbagging”. Impulse control scores above 20 are considered invalid and warrant further test investigation (ImPACT, 2013). Invalid tests are saved in the ImPACT program for future reference and it is recommended that invalid tests undergo a retest from the individual prior to full practice participation (ImPACT, 2013). For this study, impulse control scores greater than 20 were excluded from data analysis.

The six modules within the ImPACT exam are each unique and collectively evaluate upper cognitive function. First, attention and immediate memory are assessed through a word discrimination exercise. Multiple “target” words are identified from a random word bank. After identification, immediate recall of the target words are assessed
as the tester confirms the target words among similar terms. For example, the target word “ice” may be tested with the non-target word “snow”. Word discrimination is also completed at the end of the exam to evaluate delayed recall. ImPACT software provides one of five separate word lists to the tester.

Second, testers complete the design memory test. Twelve lined-shapes are presented on the screen as target shapes. Target shapes are presented twice to promote learning. Afterwards, immediate recall of the target shapes are completed by “yes” and “no” responses among similar variations. The variations are identical to the target shapes but have been rotated in space to create a new image. Shape discrimination accuracy contributes to the visual memory composite score.

The third module consists of an “X’s and O’s” matching test to address immediate memory and processing speed. A screen of distributed X’s and O’s contains three of the images highlighted in yellow. After the tester visualizes the highlighted letters, a distraction or interference test is conducted. A blue square and a red circle are each designated a specific keyboard letter. One of these shapes is displayed on the screen, cueing the tester to press the corresponding keyboard letter. After completing the interference task, the X’s and O’s image is displayed without highlights and the individual selects the appropriate letters and placement originally established prior to the interference test. This procedure is completed four times consecutively.
A fourth module evaluates processing speed, learning, and immediate memory in a symbol matching task. An adapted version of the traditional Symbol Digit Modalities Test, nine common shapes are assigned a numerical value with a reference key on the screen for identification. On the lower portion of the screen, one of the shapes is displayed for the tester. The tester then identifies the matching number assigned to the shape. After twenty-seven correct trials, the reference list disappears and the tester independently recalls the numerical assignment for each shape as it is displayed. Reaction time is also calculated within this module.

Reaction response encompasses the fifth module of the Color Match test (Stroop test). A box with a color word is displayed on the screen (e.g. RED). If the color of the font matches the color word displayed, the tester clicks the mouse to confirm. However, if a color displayed does not match the font, no action by the tester is performed. For example, the word GREEN with green font requires a click. To control for color blindness, participants confirm color interpretation prior to beginning the module.

The final module encompasses a memory test in combination with a separate interference test. Three letters are displayed across the screen for the individual to remember, then a separate screen with 5X5 grid is displayed. Random distribution of numbers 1-25 are assigned throughout the grid, the tester has eighteen seconds to click from 25-1 as fast as possible. After time has concluded, the individual recalls the three
letters previously displayed prior to the interference task. Five trials of this module are completed (ImPACT, 2013).

Symptoms were reported using the Post-Concussion Symptoms Scale (PCSS). Twenty-two symptoms commonly attributed to mTBI sequelae are self-reported on a seven point Likert scale. Researchers investigating the PCSS support the scale and its use in concussion management. (Dziemianowicz et al., 2012; Guskiewicz & Broglio, 2011; Lovell, 2009). In addition, diagnostic accuracy of determining a concussion is higher when neurocognitive scores and symptom scores are used together rather than as separate tools (Broglio, Sosnoff, & Ferrara, 2009).

Procedures

Prior to the study commencement, the Institutional Review Board (IRB) from Humboldt State University approved the study. Written consent was obtained from all participants. Minors needed parental/guardian consent, in addition to their own written assent, in order to participate in this study. Preliminary testing was administered prior to the sports’ athletic season. Valid baseline assessments were completed within one week prior to the first full-contact practice.

Participants were assigned to take the ImPACT exam in a computer lab on their respective campus. For each testing session, one hour was reserved in the campus computer laboratory. Before participants entered the room, all computer stations had the
ImPACT program ready on the desktop screen. Athletic teams were tested together in groups no larger than fifteen individuals. Participants sat at a computer with an open workspace between each test taker. All computers utilized an external mouse to navigate through the exam. An ImPACT Trained Athletic Trainer (ITAT) administered and oversaw the ImPACT testing session in accordance with the ImPACT protocol.

For the purposes of this study, the definition of a concussion from *Heads Up: Concussion in Youth Sports* initiative was summarized for the participants prior to the exam ("Heads up: Concussion in high school sports," 2012). A modification of the definition as outlined in the “Heads Up” document was created to provide a comprehensible definition.

> “Concussion is caused by a blow or jolt applied to the head or body and force is applied to the brain. This event is followed by a rapid onset of signs and symptoms that are noticeable for hours or days. Symptoms include but are not limited to: headache, dizziness, fogginess, sensitivity to light and/or sounds, and sadness. Additional complaints include feeling slowed down, irritability, and sleep difficulties.”

The test proctor guided the subjects as a group through each of the demographic, symptom, and test sections. After each subject completed the ImPACT examination, the test proctor verified test completion and the subject exited the testing environment.

All completed tests underwent inspection within the ImPACT software for invalid exams. To assist controlling for “sandbagging” attempts, an impulse control score of
twenty or more were considered invalid. Exams marked for invalidity were manually reviewed and required a retest from the individual prior to full practice participation.

Postseason testing time varied between the sports due to scheduling differences. However, all testing was completed within four weeks after the season’s final competition. The testing procedure was identical to that used during preseason testing. In addition, a separate survey was completed by all participants after completing the ImPACT test. Survey content encompassed recall questions for the complete season. Participants answered sport specific questions regarding head impacts from the athletic season. Specifically, football players reported head contacts during a typical full padded (shoulder pads, helmets, and pants), half-padded (shoulder pads, helmets and no pants), and pad free practice for the season. Soccer athletes recalled estimates for individual “heading” instances for a typical practice. All athletes also reported the number of head contacts per game. Responses for each individual were multiplied by the number of weeks in the team’s season.

**Data Analysis**

ImPACT scores were saved within the program immediately after completion of the exam. Survey results were kept in a binder locked in the Athletic Training Facility at Humboldt State University. Data for each individual was entered into IBM Statistics SPSS 21 (2012; Armonk, NY) for statistical analysis.
Subjects were grouped based on the number of concussions in a self-reported history. A one-way MANOVA was conducted comparing ImPACT composite scores between the concussion history groups. A FOUR (concussion history-0, 1, 2, 3 or more) X TWO (time- preseason, postseason) MANOVA was used to analyze ImPACT composite scores and PCSS scores between the concussion groups and between preseason vs. postseason.

**Assumptions**

All participants honestly answered postseason survey questions

Participants were adequately rested prior to exam

There was full effort for both preseason and postseason exams

**Limitations**

Concussion history and other responses from the head impact survey were self-report, and relied on accurate participant recall of personal history.

Head impact frequency and severity differ among individuals; this study did not measure head impacts

**Delimitations**
Prospective Repeated Measures Design encompassed only one athletic season in selected sports

Participants were limited to athletes between 15 and 24 years of age

**Operational Definitions**

Baseline- First neurocognitive test completed prior to the athletic season. Tester is assumed injury free and scores represent a “normal” functioning status. Future tests are compared to the “baseline” to determine whether there are clinically relevant differences between the exams.

Concussion- “Concussion is a trauma-induced alteration in mental status that may or may not involve loss of consciousness. Confusion and amnesia are the hallmarks of concussion. The confessional episode and amnesia may occur immediately after the blow to the head or several minutes later… Players commonly refer to this state as having been “dinged” or having their “bell rung.”
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Results

A total of 123 participants completed both the preseason and postseason evaluations. Thirteen participants suffered a concussion during the season and were excluded from data analysis for this study. Additional excluded participants were seven athletes who reported a learning disability (n=4) or repeated a year in school (n=3). One athlete suffered an orthopedic injury and did not participate for at least 30 days due to injury and one athlete exceeded 25 points for an impulse control score. Both of these athletes were also excluded. Final data analysis included 101 participants (n=75 male, n=26 female), age 19.09±2.54 (Table 1). The majority of participants included in this study did not have a prior concussion injury (n=53) and were included in the NoP group. Twenty-two participants reported one prior concussion injury (1P group). Both the two concussion group (2P) and three or more concussion group (3+P) each included 13 participants. The 2P group included seven soccer players and the 3+P group contained nine soccer players. A summary of demographics is presented in Table 1.

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<td></td>
<td>1 Concussion (1P)</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>2 Concussion (2P)</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>3 or more Concussions (3+P)</td>
<td>13</td>
</tr>
<tr>
<td>Sport</td>
<td>College Football</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>College Soccer</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>High School Football</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>High School Soccer</td>
<td>8</td>
</tr>
</tbody>
</table>
To evaluate the preseason neurocognitive function, a one way MANOVA was completed across four groups (IV: 0, 1, 2, 3 or more prior concussions) for five ImPACT composite scores (DV: verbal memory, visual memory, motor processing speed, reaction time, and PCSS scores). Group assignment was based on self-reported concussion history from the postseason survey.

Data did not reveal any significant differences between concussion history groups on preseason (baseline) ImPACT performance (p=0.30) However, there was an observed trend; indicating the 3+P group performed better than the NoP group at baseline. This trend was observed across the verbal memory, motor processing speed and reaction time composites (table 2).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time</th>
<th>NoP</th>
<th>1P</th>
<th>2P</th>
<th>3+P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal memory</td>
<td>Pre</td>
<td>85.5 ± 1.5</td>
<td>86.1 ± 2.3</td>
<td>86.8 ± 3.0</td>
<td>89.2 ± 3.0</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>87.3 ± 1.5</td>
<td>87.8 ± 2.3</td>
<td>87.6 ± 3.0</td>
<td>87.3 ± 3.0</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>Pre</td>
<td>75.8±1.7</td>
<td>76.7±2.7</td>
<td>81.9±3.5</td>
<td>80.4±3.5</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>80.1±1.5</td>
<td>77.4±2.4</td>
<td>80.4±3.1</td>
<td>82.5±3.2</td>
</tr>
<tr>
<td>Processing Speed</td>
<td>Pre</td>
<td>37.9±0.9</td>
<td>39.7±1.4</td>
<td>38.3±1.9</td>
<td>41.7±1.8</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>39.4±0.8</td>
<td>41.9±1.3</td>
<td>39.5±1.7</td>
<td>43.8±1.7</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>Pre</td>
<td>0.61±0.01</td>
<td>0.60±0.01</td>
<td>0.59±0.02</td>
<td>0.58±0.02</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>0.60±0.01</td>
<td>0.60±0.01</td>
<td>0.59±0.02</td>
<td>0.57±0.02</td>
</tr>
<tr>
<td>Total Symptoms</td>
<td>Pre</td>
<td>3.0±0.9</td>
<td>5.5±1.4</td>
<td>2.4±1.9</td>
<td>1.9±1.9</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>4.5±1.6</td>
<td>6.3±2.6</td>
<td>2.8±3.4</td>
<td>8.7±3.4</td>
</tr>
</tbody>
</table>
Differences in performance on baseline ImPACT composites were also examined between sports. There were no significant differences between sports on preseason neurocognitive performances, however; football players tended to score lower than soccer players across all ImPACT composites (Table 3).

Table 3. ImPACT Composite Scores and Symptoms by Sport

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time</th>
<th>Soccer</th>
<th>Football</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal memory</td>
<td>Pre</td>
<td>89.4±1.8</td>
<td>82.6±2.0</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>91.5±1.7</td>
<td>82.6±1.9</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>Pre</td>
<td>81.0±2.0</td>
<td>74.7±2.3</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>82.9±1.8</td>
<td>75.7±2.0</td>
</tr>
<tr>
<td>Processing Speed</td>
<td>Pre</td>
<td>41.9±1.0</td>
<td>36.3±1.2</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>42.7±1.0</td>
<td>38.8±1.1</td>
</tr>
<tr>
<td>Reaction time</td>
<td>Pre</td>
<td>0.58±0.01</td>
<td>0.61±0.01</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>0.57±0.01</td>
<td>0.62±0.01</td>
</tr>
<tr>
<td>Total Symptoms</td>
<td>Pre</td>
<td>3.1±1.1</td>
<td>3.0±1.3</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>4.2±2.0</td>
<td>9.1±2.2</td>
</tr>
</tbody>
</table>

A separate MANOVA was conducted within each sport. With regards to soccer, athletes with three or more concussions performed significantly better than athletes with no prior concussion injuries on the preseason verbal memory composite $F (1, 35) = 6.06$, $p=0.19$. Additionally, soccer athletes with two or more concussions performed significantly better than soccer athletes with no concussions on preseason visual memory.
EFFECTS OF CONCUSSION HISTORY ON NEUROCOGNITIVE PERFORMANCE 25

p=0.49 and reaction time p=0.47 respectively F (3, 41) =1.91. In contrast to soccer, a trend was observed among high school and collegiate football players. Athletes with three or more concussions scored worse than those with no concussions for preseason verbal memory (mean: 78.25 and 85.96, respectively) and visual memory (mean: 72.00 and 76.44, respectively) (Table 4).

Table 4. ImPACT composite scores among different sports sport within assigned concussion groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time</th>
<th>Football NoP</th>
<th>Soccer NoP</th>
<th>Football 1P</th>
<th>Soccer 1P</th>
<th>Football 2P</th>
<th>Soccer 2P</th>
<th>Football 3+P</th>
<th>Soccer 3+P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal Memory</td>
<td>Pre</td>
<td>86.0±2.0</td>
<td>85.0±2.0</td>
<td>84.9±3.2</td>
<td>87.3±3.1</td>
<td>81.1±4.3</td>
<td>91.7±4.0</td>
<td>78.2±5.3</td>
<td>94.1±3.5*</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>85.6±2.0</td>
<td>88.9±2.0</td>
<td>82.5±3.0</td>
<td>93.0±3.0</td>
<td>81.8±4.2</td>
<td>92.5±3.9</td>
<td>80.5±5.1</td>
<td>90.3±3.4</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>Pre</td>
<td>76.4±2.4</td>
<td>75.1±2.4</td>
<td>68.4±3.7</td>
<td>84.9±3.7</td>
<td>82.0±4.9</td>
<td>81.8±4.6</td>
<td>72.0±6.1</td>
<td>84.1±4.1*</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>78.8±2.1</td>
<td>81.6±2.1</td>
<td>70.0±3.3</td>
<td>84.7±3.3</td>
<td>79.8±4.4</td>
<td>80.8±4.1</td>
<td>74.0±4.1</td>
<td>86.3±3.6</td>
</tr>
<tr>
<td>Processing Speed</td>
<td>Pre</td>
<td>35.7±1.2</td>
<td>40.1±1.3</td>
<td>36.1±1.9</td>
<td>43.4±1.9</td>
<td>37.5±2.6</td>
<td>38.9±2.4</td>
<td>35.8±3.1</td>
<td>44.3±2.1*</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>38.8±1.1</td>
<td>40.0±1.1</td>
<td>38.2±1.8</td>
<td>45.6±1.8</td>
<td>39.7±2.3</td>
<td>39.3±2.2</td>
<td>38.3±2.0</td>
<td>46.2±2.0</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>Pre</td>
<td>0.62±.01</td>
<td>0.60±.01</td>
<td>0.63±.02</td>
<td>0.56±.02</td>
<td>0.59±.03</td>
<td>0.59±.03</td>
<td>0.62±.04</td>
<td>0.57*±.03</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>0.61±.01</td>
<td>0.59±.01</td>
<td>0.64±.02</td>
<td>0.56±.02</td>
<td>0.62±.03</td>
<td>0.58±.03</td>
<td>0.62±.03</td>
<td>0.54±.02</td>
</tr>
<tr>
<td>Total Symptoms</td>
<td>Pre</td>
<td>2.7±1.3</td>
<td>3.2±1.4</td>
<td>6.1±2.1</td>
<td>4.9±2.1</td>
<td>2.0±2.8</td>
<td>2.7±2.6</td>
<td>1.0±3.5</td>
<td>2.2±2.3</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>3.9±2.3</td>
<td>5.1±2.3</td>
<td>3.8±3.6</td>
<td>8.9±3.6</td>
<td>4.8±4.8</td>
<td>1.0±4.5</td>
<td>23.7±5.9†</td>
<td>2.0±4.0</td>
</tr>
</tbody>
</table>

Note:* Soccer players with 3+ concussions performed better than athletes with no prior concussions(p<.05). †Football players with at least 3 concussions had greatest increase in PCSS between testing intervals (p<.05)
Additionally, sex differences were noted in that males tended to perform worse than females on preseason verbal memory, motor processing speed, and reaction time across all concussion groups (Table 5). However, these differences were not statistically significant.

The secondary aim of this study was to examine differences between preseason and postseason composite scores. Across all ImPACT concussion history groups, there were no significant differences among preseason to postseason scores (Table 2). Preseason and postseason values are also depicted in figures 1-5. Athletes with two or fewer prior concussions tended to show improvements in verbal memory composite score on the ImPACT test postseason as compared to preseason (p>.05). As the number of prior concussions increased the improvements in verbal memory scores tended to be reduced; although not significant. In contrast to the other groups, the 3+P group tended to decline in verbal memory score between pre and post testing sessions (p>.05) (Table 2, Figure 6.). Moreover, college football players with 3+ concussions tended to perform worse than other concussion history groups on postseason verbal memory. However, this small size group (n=2) obtained the highest postseason scores on visual memory and motor processing speed compared to other concussion history groups (Table 4).
Table 5. ImPACT composite scores between sex across concussion groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time</th>
<th>NoP Males</th>
<th>NoP Females</th>
<th>1P Males</th>
<th>1P Females</th>
<th>2P Males</th>
<th>2P Females</th>
<th>3+P Males</th>
<th>3+P Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>85.6±3.0</td>
<td>87.0±2.0</td>
<td>87.4±4.0</td>
<td>87.1±3.8</td>
<td>82.0±7.6</td>
<td>87.7±3.9</td>
<td>92.6±6.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>87.9±2.9</td>
<td>87.2±2.9</td>
<td>89.2±3.4</td>
<td>92.5±3.9</td>
<td>89.0±3.7</td>
<td>95.5±7.4</td>
<td>83.7±3.7</td>
<td></td>
</tr>
<tr>
<td>Verbal Memory</td>
<td>Pre</td>
<td>81.5±3.5</td>
<td>72.7±3.5</td>
<td>76.4±4.1</td>
<td>73.8±3.6</td>
<td>79.0±8.9</td>
<td>76.5±4.5</td>
<td>81.3±7.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>82.4±3.0</td>
<td>79.3±3.1</td>
<td>86.4±4.7</td>
<td>88.1±4.1</td>
<td>82.0±3.9</td>
<td>82.0±7.8</td>
<td>78.8±3.9</td>
<td></td>
</tr>
<tr>
<td>Visual Memory</td>
<td>Pre</td>
<td>38.7±1.7</td>
<td>37.4±1.7</td>
<td>39.4±2.0</td>
<td>44.3±2.2</td>
<td>42.8±4.3</td>
<td>38.7±2.2</td>
<td>43.6±3.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>39.3±1.6</td>
<td>41.0±1.6</td>
<td>41.3±1.9</td>
<td>46.1±2.2</td>
<td>40.6±2.1</td>
<td>41.4±2.1</td>
<td>43.3±3.4</td>
<td></td>
</tr>
<tr>
<td>Processing Speed</td>
<td>Pre</td>
<td>0.61±0.02</td>
<td>0.59±0.02</td>
<td>0.63±0.02</td>
<td>0.54±0.03</td>
<td>0.56±0.03</td>
<td>0.55±0.05</td>
<td>0.60±0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>0.57±0.02</td>
<td>0.62±0.02</td>
<td>0.65±0.02</td>
<td>0.53±0.02</td>
<td>0.57±0.02</td>
<td>0.53±0.05</td>
<td>0.59±0.02</td>
<td></td>
</tr>
<tr>
<td>Reaction Time</td>
<td>Pre</td>
<td>2.2±1.9</td>
<td>4.2±1.9</td>
<td>5.1±2.2</td>
<td>5.4±2.6</td>
<td>2.5±2.4</td>
<td>1.0±4.9</td>
<td>1.4±2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>3.1±3.1</td>
<td>7.0±3.1</td>
<td>4.8±3.6</td>
<td>9.8±4.2</td>
<td>3.0±3.9</td>
<td>1.5±7.9</td>
<td>16.4±4.0</td>
<td></td>
</tr>
<tr>
<td>Total Symptoms</td>
<td>Pre</td>
<td>2.2±1.9</td>
<td>4.2±1.9</td>
<td>5.1±2.2</td>
<td>5.4±2.6</td>
<td>2.5±2.4</td>
<td>1.0±4.9</td>
<td>1.4±2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>3.1±3.1</td>
<td>7.0±3.1</td>
<td>4.8±3.6</td>
<td>9.8±4.2</td>
<td>3.0±3.9</td>
<td>1.5±7.9</td>
<td>16.4±4.0</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Preseason and postseason verbal memory composite scores (Mean ± SEM) in different concussion history groups. No significant differences between concussion groups or between pre and post season were observed.
Figure 2. Preseason and postseason visual memory composite scores (Mean ± SEM) in different concussion history groups. No significant differences between concussion groups or between pre and post season were observed.
Figure 3. Preseason and postseason motor processing composite scores (Mean ± SEM) in different concussion history groups. No significant differences between concussion groups or between pre and post season were observed.
Figure 4. Preseason and postseason reaction time composite scores (Mean ± SEM) in different concussion history groups. No significant differences between concussion groups or between pre and post season were observed.
Figure 5. Preseason and postseason symptom scores (Mean ± SEM) in different concussion history groups. No significant differences between concussion groups or between pre and post season were observed.
Figure 6. Change in verbal memory score from preseason to post season among concussion history groups.
Improvements in ImPACT scores over the course of a season were most notable for the motor processing composite (Table 2). All concussion history groups tended to improve in motor processing speed from preseason to postseason evaluation (p>.05). The improvement in motor processing speed for college soccer players with 3+ concussions (n=9) was significantly greater than collegiate soccer players with no previous concussion injuries [F(3, 45) = 3.52 p=.023].

Although not a significant change, all concussion groups reported a higher symptom score compared to baseline examination (p>.05) with the 3+P group having the greatest increase in symptoms (p>.05). More specifically two high school football players with 3+ concussions self-reported a significantly higher increase of symptoms compared to all other concussion history groups F (3, 18) = 4.09 p=.022.

Results from self-report head impact exposure questions are identified in Table 6. Specific to soccer, defenders and forwards experienced the most “heading” episodes during the soccer season. Football offensive and defensive lineman also reported the highest amount of head contacts compared to other position groups. There were no observed relation between head contacts and changes in ImPACT composite scores (r²=0.031).
Table 6. Head impacts during a season for different sports and player positions.

<table>
<thead>
<tr>
<th>Sport</th>
<th>Position</th>
<th>Contacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer</td>
<td>Defender (n=15)</td>
<td>1735.8±1182.7</td>
</tr>
<tr>
<td></td>
<td>Midfield (n=24)</td>
<td>949.3±1215.8</td>
</tr>
<tr>
<td></td>
<td>Forward (n=10)</td>
<td>1648.7±1010.7</td>
</tr>
<tr>
<td></td>
<td>Keeper (n=4)</td>
<td>150.0±219.4</td>
</tr>
<tr>
<td>Football</td>
<td>Running Back/Linebacker (n=9)</td>
<td>301.4±611.4</td>
</tr>
<tr>
<td></td>
<td>Receiver/Defensive Back (n=19)</td>
<td>141.2±170.2</td>
</tr>
<tr>
<td></td>
<td>Offensive/ Defensive Line (n=24)</td>
<td>460.1±497.6</td>
</tr>
</tbody>
</table>
Discussion

For this study, we hypothesized an association between multiple concussions and neurocognitive function deficits. Athletes with three or more concussions were predicted to perform worse than those with no prior injuries before an athletic season. We also predicted postseason decrements in athletes with a greater number of concussion injuries. The results refute both outcomes originally predicted for this study. Athletes with three or more concussions did not obtain lower preseason (baseline) scores than athletes without a history of concussion. Furthermore, there were no significant changes from preseason and postseason composite scores across any concussion group. However, there were several notable trends and comparative findings worth mentioning.

Potential long term neurocognitive and psychological effects of mTBI and subconcussive forces exposure are growing international concerns. A highlighted consideration in concussion management is the dose-response relationship between prior concussion injuries and long term patient outcomes. Athletes with the greatest history of prior concussions exhibit lower objective performances and higher symptom reporting when compared to those with fewer injuries (Brooks et al., 2013; Collins et al., 2002; Covassim, Moran, & Wilhelmy, 2013; Guskiewicz et al., 2003; Gysland et al., 2012; Iverson, Echemendia, Lamarre, Brooks, & Gaetz, 2012; McAllister et al., 2012; Talavage et al., 2013). Some investigators speculate that prior concussion injuries may lower the concussion injury threshold for subsequent head impacts (Collins et al., 2002). This dose-response relationship is well documented among current researchers and has literary
support (Covassin et al., 2010; Elbin et al., 2013; Guskiewicz et al., 2003; Matser, Kessels, Lezak, & Troost, 2001). If the threshold is decreased in individuals who experience more concussions then they may respond to subconcussive impacts differently than those who have no prior injuries. Subconcussive forces combined with a dose-response relationship are a potential cause for later life neurodegeneration. Evidence suggests former NFL players are at a higher risk than the general population for succumbing to neurodegenerative mortality (Daneshvar et al., 2011; Gavett et al., 2011; Khurana & Kaye, 2012; Langlois et al., 2006; Lehman, Hein, Baron, & Gersic, 2012; Rabadi & Jordan, 2001). This relationship can be supported by measures such as neurocognitive testing. Some researchers detected neurocognitive impairments in former NFL players (Randolph, Karantzoulis, & Guskiewicz, 2013). However, the amount of longitudinal studies investigating cumulative impacts in individuals with prior concussion injuries is limited, and evidence to support or refute a dose-response relationship was mixed (Collins et al., 1999; Gysland et al., 2012; Kaminski, Wikstrom, Gutierrez, & Glutting, 2007; Miller et al., 2007).

The findings from this current study indicate several points regarding the interaction of prior concussions and contact sport participation on cognitive function. In contrast to the previous studies mentioned, individuals with a greater number of concussions did not perform worse than individuals with fewer concussions on baseline neurocognitive measures. In fact, all participants performed within the reliable change indices for all ImPACT composite outputs regardless of concussion history. These results
Contradict several studies that observed decreased neurocognitive scores among athletes with a history of multiple concussions on preseason evaluation (Collins et al., 2002; Covassin et al., 2013; Guskiewicz et al., 2003; Iverson et al., 2012). Discrepancies between our results and those of prior researchers shed light on the importance to investigate prior concussion history on neurocognitive performance.

Moreover, the results of this study show that participation in football and soccer for one athletic season had no deleterious effects on neurocognitive function in individuals with a history of prior concussions. These findings are consistent with those of other researchers who investigated the effects of prior concussion history on neurocognitive function after a season of contact sport (Brooks et al., 2013; Kaminski et al., 2007; Miller et al., 2007). Brooks et al. (2013) observed increased symptoms in hockey players with more concussions than athletes with no prior concussions after completing a season. However, no ImPACT composite scores were significantly different among any participants. Miller et al. (2007) presented similar conclusions in a population of football players. Kaminski et al. (2007) used a separate neurocognitive evaluation, but did not observe differences among soccer players with more prior concussion injuries. Our study is unique for including both soccer and football into one repeated measures design.

One possible explanation for discrepancies among this study and results of prior researchers is the time length between the last head impact exposure and examination. Postseason measures were administered an average of 17 days after the final competition.
Similar longitudinal studies that provided assessment data conducted postseason testing beyond twenty days after the final game (McAllister et al., 2012). Despite our effort to decrease the length of time between final contact and testing, any potential alterations to neurocognitive function may have already been restored. This may be attributed to the resolution of the concussion neurometabolic cascade. This phenomenon is characterized by an alteration in neuron charge mediator and neurotransmitter levels. Typically, the stoichiometric relationship between intracellular and extracellular ions will be restored within the first 10 days (Giza & Hovda, 2014). There is some evidence to show the majority of individuals who experience a single concussion have somatic improvement after the initial two weeks (McCrory et al., 2013). Furthermore, athletes recovering from acute concussion injury may recover normal brain function after symptoms resolve (Elbin et al., 2012). Cumulative subconcussive forces applied to the brain may trigger small alterations in metabolic function that can resolve well before our neurocognitive test is administered. One group of researchers identified 70% of football players performed worse on at least one ImPACT composite within the first two days of the season’s conclusion (Mulligan, Boland, & Payette, 2012). A study of collegiate football athletes noted significant increases in reaction time 14 days after the season’s conclusion (Miller et al., 2007). Observed findings within the first week after the season’s conclusion in Mulligan’s (2012) study may offer insight into our results. Resulting biological alterations from subconcussive forces possibly restored prior to our post season evaluation. Future investigators should consider the duration between final head contact exposure and neurocognitive assessment.
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There is limited relevance to the areas of noted differences among preseason and postseason changes. Differences may have been noticed but were not outside the reliable change index (RCI) for the corresponding composite scores. Prior researchers have reported indices for each ImPACT composite among high school and college aged athletes (Covassin, Elbin, Stiller-Ostrowski, & Kontos, 2009; Elbin, Schatz, & Covassin, 2011). An 80% confidence value is designated for each score and significant changes beyond the RCI value are clinically significant. For this study, all differences among preseason and postseason changes were within the RCI for all composites.

**Sex Differences**

Observing sex differences in response to mTBI may be a guide to determining ideal concussion management strategies. The results from our study support sex differences in neurocognitive function. Males tended to perform worse than females on several ImPACT composite scores when matched on self-reported concussion history. This observation was seen across both preseason and postseason evaluations. Prior findings have also supported sex differences on neurocognitive function (Elbin et al., 2012). However, it is difficult to determine if our sex discrepancy is sport related or sex related, as there was no female football group for comparison. Football and soccer participants are exposed to body and head impact forces unique to each sport, dependent on game strategy (Naunheim, Standeven, Richter, & Lewis, 2000). Both sports do involve repetitive exposure to concussive and subconcussive forces, e.g. tackling and soccer heading, which distinguishes them from sports with less overall exposure. It is
worth noting that soccer and football have the highest rates of reported concussions for
high school and collegiate sports (Naunheim et al., 2000). Still, comparisons between
sexes require more participants to provide separate groups with the appropriate
qualifications for the statistical analysis. For instance, researchers may compare sex
differences within separate concussion history groups among the same sports.

The results from this study further support the practicality of using the ImPACT
examination in assessing individuals suspected of a concussion injury within the initial
days following injury. The ImPACT program is valid in assessing initial neurocognitive
effects of concussion within the first seventy-two hours of injury (Schatz & Sandel,
2013). Our population did not experience a concussion during the season; As such, non-
concussed performance remained consistent across all participants among preseason and
postseason composite scores. No outcomes between time intervals were statistically
significant and outside the RCI for ImPACT. This finding provides further support for the
ImPACT program in assessing post injury neurocognitive function.

Despite differences in our findings, the proportion of participants in each
concussion history group was consistent with previous studies and not likely the reason
for variation between results. Moser et al. (2005) observed concussion histories across
several male and female sports including both soccer and football. Among the study
population, 25% experienced one concussion and 20% suffered at least two or more
concussions. Covassin et al. grouped their athletic populations similarly, as those who
experienced one concussion (26%), two concussions (12%), and three or more
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concussions (11%) (2013). Our population consisted of individuals with one, two, or three or more concussions as 21%, 12%, and 12% respectively.

Subconcussive Forces

Subconcussive forces are considered a potential factor in regards to cognitive and psychological deficits observed in individuals. Our study aimed to examine this relationship via self-reported head impacts during the season in comparison to ImPACT changes among the preseason and postseason composite scores. The offensive/defensive line groups experienced the greatest number of head impacts during the season. This subgroup of football athletes is most likely to experience the most head contacts. Various authors have also identified lineman receiving more head impacts than other football positions (Broglio, Sosnoff, Shin, et al., 2009; Gysland et al., 2012). Among our study, no correlation was noted between contact exposure episodes and changes in neurocognitive scores across all ImPACT composites.

Adolescents have been shown to respond differently than adults to concussions (Field, Collins, Lovell, & Maroon, 2003). mTBIs may negatively affect brain plasticity in adolescents more than adults due to accelerated rate of brain development in this population (Moser et al., 2005). For these reasons, medical providers emphasize a more conservative treatment approach for this population. Coincidentally, recently adopted California legislation was submitted prior to our study commencement to address this concern. ("Interscholastic Sports: full-contact football practices: concussions and head
Surprisingly, we found the two high school athletes from the 3+P group reported the highest symptom increase after the season compared to other groups. Prior injury history and cumulative head impact exposure may explain the dramatic increase in symptom score. This may reveal a subgroup of adolescent athletes that requires further investigation.

Limitations

Self-report data. Our study was limited to self-report values provided on a postseason survey during the second testing session. Though our group samples were consistent with other researchers, it is problematic to determine if prior concussions influence neurocognitive function based on self-report data. Athletes were self-reporting previous concussion history based on the definition of a concussion given for this study, which is subject to different interpretations. Self-report measures are also subject to recall bias and evidence reports the presence of underreporting in this population (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004; Register-Mihalik et al., 2013). Furthermore, self-reporting of symptoms or concussion history has shown to vary between written and interview approaches. Prior evidence suggested written responses report higher concussion symptoms than interviewer methods (Krol, Mrazik, Naidu, Brooks, & Iverson, 2011). Based on these conclusions, we attempted to delimit the self-report data by implementing a survey to obtain a consistent response among participants. Nevertheless, self-report data is not an accurate approach to determine concussion history.
or head contacts. Further researchers should examine alternative methods to obtain this critical information.

Self-report response evaluation was also a limitation while observing head impact exposures at the season’s conclusion. But this method does not provide ideal validation of the cumulative forces athletes experience during sport participation. Evidence suggests college football players significantly underreport head contacts during a season, with the greatest degree of underreporting in offensive and defensive lineman (Baugh et al., 2015). This position group reported the highest number of head contacts in the season compared to other position groups. But the true incidence of head impacts may be higher than our study analyzed. Future investigators should incorporate accelerometer data to accurately identify the number of head collisions in football players.

The dose-response relationship between prior concussions and neurocognitive function is supported by self-reported data. It is difficult to use broad descriptions to reliably categorize individuals into specific groups. Concussion sequelae affect sleep, balance, and/or cognitive areas of brain function. Assuming criterion variables without the appropriate reliable methods may limit the internal validity of research studies.

**Testing specificity.** Though changes in score were observed for select composite scores among our participants, the fluctuations in scores were still within the RCI for many of the composite scores. In other words, the fluctuation in scores observed for different composites were within a normal/baseline range. The error variance of the ImPACT examination allows considerable changes for both improvements and deficits in
composite score outputs deemed within the normal range. Cognitive function as a construct is a complex communication network between different portions of the brain. As such, accurately measuring neurocognitive function is a difficult task to complete. Ideally, a neurocognitive examination intended to investigate effects of subconcussive forces needs to be sensitive to discrete variations in processes. Further research would be improved from assessment tools that are more sensitive to neurocognitive function.

Furthermore, methods to more accurately measure specific areas of cognitive function/memory/equilibrium after an injury would be beneficial. Future researchers should try to identify and isolate distinct areas of cognitive function affected by concussions and investigate their role in recovery. Our study observed a negative trend in concussion history and verbal memory after an athletic season. Several authors support the argument that repetitive head impacts can adversely affect higher learning (Collins et al., 1999; McAllister et al., 2012; McCrory et al., 2013). A concussion expert consensus recently reported greater effects in memory and motor processing speed than other components that may be affected by concussion injuries (Medicine & Council, 2014). Perhaps, a component within the processes in verbal memory can play a pivotal role in memory recollection that is affected by cumulative brain injuries. As previously mentioned, there is still a need to detect subtle differences in cognitive function that may result from cumulative head injuries.

Safety representatives supported a multifaceted approach to managing head injuries at a recent international conference (McCrory et al., 2013). A recent
neurocognitive examination review expressed the importance of including a comprehensive concussion evaluation and treatment approach (Kontos, Braithwaite, Dakan, & Elbin, 2014). Our study incorporated solely neurocognitive objective measures. This limitation should be recognized, and we agree with prior investigators who promote the use of vestibular combined with neuropsychological evaluations (Littleton & Guskiewicz, 2013; West & Marion, 2014).

It is difficult to substantiate cognitive changes over the course of a single athletic season. Understanding the potential effects of concussion history and head contact exposures on cognitive function will require a larger population and more competitive seasons. Longitudinal studies encompassing several years may provide important data to researchers investigating effects of cumulative mTBI.

**Head Impacts.** In order to better understand the relationship between head impact exposure and neurocognitive function researchers should explore the use of accelerometers for quantifying incidence and magnitude of head impacts. Athlete recall on the number of hits sustained during a season provides insight into cumulative head impact exposure. However, self-report data does not provide quantifiable head impact exposure values such as force magnitude, hit location, and time intervals between subsequent hits. These potentially influential variables limit our knowledge on cumulative subconcussive forces and warrant the need for further investigation. Accurate head impact exposure data may guide other researchers in better understanding these phenomena. A thorough analysis on subconcussive forces is required to establish a
relationship between hits experienced during a typical season and short term neurocognitive function.
Conclusion

The implications of a dose-response relationship for concussion injury as a potential factor for later life neurocognitive impairment are profound. For individuals participating in contact sports, the risk of experiencing a mTBI is increased across various age groups and competitive levels. While findings from this study did not show significant changes in neurocognitive test scores after a single competitive soccer or football season, there were a number of observed trends that shed light on the importance of comprehensive large scale longitudinal studies.
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Appendix

Survey

Background

What is your name?

What is your age?

What is your gender?

What school do you attend?

What Sport did you play this season?

__ High School Football

__College Football

__High School Soccer (Men's)

__High School Soccer (Women's)

__College Soccer (Men's)

__College Soccer (Women's)

Football

How many years have you participated in your sport competitively?

How many concussions have you experienced? (Includes "dingers" and "bell rung")

What position did you most often play this season?

__Offensive Lineman/Defensive Lineman (Center, Guards, Tackles, Defensive Ends)
__Running Back, Linebacker, Tight end
__Receiver, Defensive Back, Quarterback
__Special Teams Player (Kicker, Punter)

How many minutes did you play in a regulation game (48 min)?

How many games did you play in this season?

Did you have any concussion injuries during this season?
  __No
  __Yes

How many days did you sit out from full participation because of the concussion injury?

How many full pads practices (helmet, shoulder pads, padded pants) do you have per week?

On average, how many times do you receive head impacts in a full pads practice?

How many half-pad practices (helmet, shoulder pads, shorts) do you have per week?

On average, how many times do you receive head impacts in a half-pads practice?

How many pad-free practices (helmet/no helmet, no shoulder pads, shorts) do you have per week?

On average, how many times do you receive head impacts in a pad-free practice?

Did you have access to a health care professional who was trained to recognize/manage a concussion (Doctors, certified athletic trainers, neuropsychologist, etc.)?
  __Yes
  __No

Soccer
How many years have you participated in your sport competitively?

How many concussions have you experienced? (includes "dingers" and "bell rung")

What position do you most often play?

- Forward/Striker
- Midfield
- Defense (Sweeper, Stopper, Backs)
- Keeper (Goalie)

On average, how many minutes did you play in a regulation game (90 min)?

How many games did you play in this season?

Do you consider yourself as a “header” or someone who frequently heads the ball?

On average, how many times do you “head” the ball in a practice?

How many practices do you have per week?

On average, how many times do you “head” the ball in a game?

Did you have access to a health care professional who was trained to recognize/manage a concussion? (Doctors, certified athletic trainers, neuropsychologists, etc.)