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The Effects of Repeated Sub-Concussive Impacts on Reaction Time Across a Football Season

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The Effects of Repeated Sub-Concussive Impacts on Reaction Time Across a Football Season

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Abstract

Context: Recent evidence suggests an accumulation of head impact exposures may influence neurocognitive functioning over time. Objective: The purpose of this study was to analyze the relationship between sub concussive impacts and reaction time in collegiate football players across a football season. Design: Observational cohort study. Setting: Data was collected at a NCAA Division III college throughout the 2022 competitive football season. Participants: 25 players volunteered for the study. Main Outcome Measures: HIE (99%,95%, <95% threshold categories) collected by helmet accelerometers and Sway© RT measures (RT, IC, IT) collected at preseason (BL) and post season (Post). Results: 25 subjects recorded a total of 5875 HIES (235±174.42). Correlation tests showed a statistically significant positive relationship between MHIEs and ΔRT (r=.420, p=.036). Statistically significant negative correlations were found between THIEs and ΔIT (r= -.422, p=.036), LHIEs and ΔIT (r= -.400, p=.047), and MHIES and ΔIT (r= -.450, p=.024) Conclusion: Sub-concussive impacts occurred at a higher prevalence throughout the study than concussive impacts. Changes in RT were demonstrated in the study group, but further research is needed to validate the effects of sub-concussive forces on these changes. This study contributes to the ongoing research of HIE and neurocognitive assessments in collision sports such as Division III collegiate football. Word Count: 202 words Key Words: Head impact exposure, reaction time, football, accelerometers

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Review of Literature

Introduction

A concussion is defined as an alteration in mental status caused by a traumatic injury or blow to the head.[1,2] This alteration in mental status presents with at least one of a range of symptoms, including headache, nausea, vomiting, dizziness, balance problems, fatigue, difficulty sleeping, drowsiness, sensitivity to light or noise, blurred vision, memory problems, and difficulty concentrating.[2] Concussions are one of the most common injury occurring in sports, recreational activities, and activities of daily living.[3] In fact, an estimated 3.8 million concussions happen in sport settings and recreational events every year.[3] This lead to the development of a more precise term to define concussions occurring outside activities of daily living, known as sport related concussion (SRC). The SRCs are distinct from other concussions as they commonly result from low-velocity impacts and present without obvious confusion and disorientation.[4] There is a high prevalence of SRCs in sport activity that has led to a focus of research in this area. Specifically, the sport of American football has been identified as a high-risk, repetitive collision activity that reports one of the highest numbers of SRCs each year.[5]

A subconcussive impact is classified as mild brain trauma that does not result in the clinical diagnoses or presentation of a concussion.[6,7] It is believed that accumulated subconcussive impacts can express effects later in life, due to accrued anatomical and physiological damage.[5,6] Due to the lack of symptoms associated with subconcussive impacts, there has been a focus on collecting objective information on these head impact exposures (HIEs). One way this is being explored in the literature is through helmet accelerometer sensors, which allow the collection of head impact characteristics[6] such as location, frequency, and magnitude in American Football players.

In the sport of American football there are a combination of diagnosed SRCs and undetected subconcussive impacts. Both these types of HIEs can present an array of findings. Between the two, SRC's more commonly display a decrease in neurocognitive functioning, while subconcussive impacts do not [1,2,6] One of the most sensitive indicators of a change in neurocognitive ability is a prolonged reaction time (RT).[7] Researchers and health care providers collect RT data in 2 main ways, either clinically or digitally through a computerized test. The most used computerized test is the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).[15] The ImPACT test gathers data on self-reported concussion symptoms as well as neurocognitive functioning. This is done through a series of modules, focusing on attentional processes, visual and verbal memory, numerical sequencing ability, and reaction time. Other computerized tests, like Sway©, collect further data on different aspects of RT such as simple reaction time (SRT), impulse control (IC), and inspection time (IT).[8] These measures, when used in conjunction with one another, can indicate changes in neurocognitive function in an individual, even in the absence of clinical symptoms related to concussions. To fully appreciate the complexities of these topics, the overarching subject of concussions will be explored in detail.

Concussion

Pathophysiology

Concussions, also referred to as mild traumatic brain injuries (mTBIs), are a serious injury on the brain injury spectrum.[8] Along with this distinction, links in the research have been found between repetitive concussions and chronic conditions such as Alzheimer's disease, depression, epilepsy, and chronic traumatic encephalopathy (CTE).[8-10]

Mechanical forces disrupt cellular homeostasis in the brain, initiating an acute neurometabolic cascade and biochemical alterations.[11] One of the first markers of this cascade is sudden depolarization of neurons, resulting in the release of excitatory neurotransmitters that cause cell damage by creating an influx of intracellular sodium and calcium.[11] Injury to the brain also acutely results in a cellular energy crisis, as glucose metabolism is decreased for 5 to 10 days post injury.[11] Following these events in the acute setting, subacute impaired synaptic plasticity, blood-brain barrier disfunction, and neuroinflammation can occur.[11] Neuroinflammation is been hypothesized to correlate with the symptoms and their duration following a concussive HIE.[11]

Chronic traumatic encephalopathy is a neurodegenerative disease associated with repetitive brain trauma and the neurometabolic changes that come with it. Symptoms including memory impairment, depression, irritability, impulse control problems, and aggression and increased violence.[8] Diagnosing criterion for CTE relies on neuropathological changes such as decreased brain weight and an increase in phosphorylated tau proteins. Unfortunately, this means it can only be detected postmortem.[8] To date, this disease has only been found in individuals who had a history of repeated brain trauma,[9] such American Football players.

Signs and symptoms

Common signs seen in an athlete who has sustained an SRC includes loss of consciousness (LOC), retrograde or anterograde amnesia, disorientation, poor physical coordination, imbalance, seizure, and changes in personality.[12] Patient symptoms may include headache, dizziness, nausea, photophobia, phonophobia, tinnitus, drowsiness, sadness, or hallucinations,[12] with headaches and dizziness being the most common.[13] Neuropsychological testing consistently shows deficits that also occur within the window post injury of 1 to 2 weeks, with some suggesting deficits lasting up to 6 months.[14] Risks associated with self-reported data is underreporting of concussions and their symptoms. Players may withhold information for many different reasons, ranging from lack of education on symptoms, not thinking it is serious enough for medical attention, and not wanting to miss playing time. [2,10]

Assessment, Diagnosis, and Return to Play

Assessment of a concussion should begin before an HIE even occurs, as baseline testing is suggested by the NATA for all participants in sports where concussions are likely.[2] Testing should include a documented neurologic history with symptoms and a physical exam, as it aids the clinician in the diagnosis of an SRC.[2] Factors that a clinician should evaluate when a concussion is suspected include muscle strength, motor control, eye examination, mental status, symptoms, and cognitive functioning.[2] Current evidence supports the modification to sport activity following a concussion to reduce the likelihood of a second injury within the window of vulnerability, also known as "second impact syndrome".[2, 16] This rare, but often fatal condition is present with malignant uncontrollable cerebral edema and increased intracranial pressure. [4,16, 17]

Return to play (RTP) decisions should not start until the athlete no longer reports symptoms related to concussions, has a normal clinical examination, and performs at or above baseline on all objective concussion assessments.[2,18] The athlete should follow a preset concussion return to play protocol, usually lasting 5 to 7 days. These days, or stages, should progress in both time and intensity as the player advances.[1,2] The first day is no activity, which then progresses to light activity, then to noncontact sport specific activities, and finally to unrestricted training before being cleared to return to play.[2] If patient develops symptoms at any point in a stage activity should be halted and the stage be repeated the following day.[1,2]

Epidemiology and Population Specifics of SRC

Research suggests that athletes participating in sports where the chance of head collisions is greater, such as American football, are at higher risk for sustaining concussions.[10, 19] With a total of over 70,000 collegiate level players and over 1 million high school players, American Football is one of the most popularly played sports in the nation.[19] This large sample size allows for large-scale research. In fact, some research has found that participants in National Collegiate Athletic Association (NCAA) Division III football had a higher rate of concussions, 5.26 per 1000 exposures, than Divisions I and II, 3.7 and 3.21 respectively.[13] Reinjury among this population is common as well, as football players with a self-reported history of 3 or more concussions were 3 times more likely to sustain a concussion than players without a history.[13]

Age influenced the number, magnitude, and severity of impacts. High school football players sustained up to 3 times as many impacts as youth participants, and those in college sustained 1.8 times the high school population, [20]Therefore, it is relevant to focus on this population when we are evaluating themes associated with concussive and sub-concussive events over time. Specifically, an area of focus is the impact of collision activity on reaction time.

Reaction Time

Included in both baseline and post injury testing, a slowed RT can indicate a decrease in neurocognitive functioning. Reaction time following an SRC is one of the most sensitive indicators of neurocognitive functioning., and RT deficits may persist beyond symptom resolution.[7] In addition, Eckner et al found that concussed athletes have slower reaction times than non-concussed athletes.[7] Similarly, they found that RT as an independent measure had a sensitivity of 79% and a specificity of 61%.[7]

Measurement systems and tools

Like the risk of under-reporting symptoms on checklists, athletes may try to hide indicators of impairments by suppressing scores at baseline.[21] Such computerized testing tools can be valuable, but computer-dependence, time requirement, and cost limit their applicability in acute concussion diagnosis situations or in communities with limited financial resources.[22]

ImPACT©

Multiple commercially available computerized tests collect data on neurocognitive functioning at baseline and allow for retesting after a concussion. One of the most widely used of these assessments is the ImPACT©. This test stems from the clinical paper-and-pencil reaction time tests and is subdivided into the following 5 subtests; verbal memory, visual memory, visual motor speed, reaction time, and total symptom score.[17,24] A study by Schatz and Sandel reported a high sensitivity of 94% and a moderate sensitivity of 69% for the ImPACT© in the acute setting.[21]

Sway©

Sway© motion reaction time assessment is a measure of basic sensory processing and speed of neuromuscular response.[23] Sway© gathers data on 3 subdivisions of reaction time. The first is SRT, measured by the individual's ability to detect a change in a color of the screen and move the device as a response. [23] The time between the color change and the user-initiated tilt of the device is recorded 5 times during 1 test.

The next subset Sway© assesses is impulse control, which quantifies the ability of an individual to respond to a go stimulus with a motor response, or a no-go stimulus requiring no response.[23] This requires an individual to rapidly move the device when a target is presented on the screen.

Finally, inspection time is assessed. This involves the users touching the side of the screen with the longest line after the lines have left the screen.[23]The duration of time before the lines is masked is reduced as the trials continue. In the literature, Sway© SRT trials have demonstrated a high intraclass correlation coefficient (ICC) of .713 without a statistically significant difference in results from repeat trials.[28]

Normative values for RT differ significantly between males and females. Data also shows an improvement in late childhood, a plateau during early adulthood, and then a steady decline due to age.[23] This shows that college aged athletes should be performing at their peak RT, and any decrease in RT or potential causes of decrease should be investigated.

Sub concussive Impacts

Despite the strong understanding of the role that an SRC has on reaction time and other objective, measurable signs of a concussion, it is less understood how repeated subconcussive events may impact reaction time. Like concussions, subconcussive impacts involve a transfer of mechanical energy to the brain.[9] Research suggests that head impacts chat do not develop symptoms or visible signs of neurological dysfunction occur in contact and collision sport.[24] This lack of signs and symptoms often leads to there being no clinical diagnosis of a concussion, however changes can be seen in biophysics data, neuroimaging, and forensic analysis.[24] Data of studies that focused on subconcussive forces found no clinically meaningful changes from preseason to post season on neurological functioning.[27] Despite this, other findings have shown a decrease in performance of those in contact sports compared to those outside of contact sports.[28] In addition, neuroimaging studies shows that over the course of one football season there were changes in cerebral blood flow patterns, brain connectivity, and the presence of microhemorrhage linked to repetitive impacts.[25]

Helmet Accelerometer technology

The mandatory use of helmets in American football has allowed for the measurement of forces, velocities, accelerations, and frequencies of head impacts in real time. [21] Riddell Head Impact Telemetry System (HITS) is among the most used devices in head impact research in football.[16, 20] This HITS device uses 6 single-axis accelerometers that fit inside the football helmet.[20] For the HITS to record an impact, any of the 6 sensors must measure a force of 14.4g. When recorded, this data is filtered to only include hits values of linear Acceleration that exceeded 10g Though the literature has not found a cutoff value for linear acceleration or force values required for a concussion to develop, concussive impacts have been associated with linear magnitudes ranging from 69.7g to 145g. [20] Experiments also show that rotational acceleration caused shear strains to brain tissue resulting in concussion.[18]Other attempts to correlate injury variables such as peak acceleration have proven inadequate in their ability to accurately predict the occurrence of concussion. [10,11] However, helmet sensors have been shown to inflate the values of true head acceleration by up to 10 times.[17] Acceleration is important as the velocity of impacts play an important role in the incidence of concussion.[26,27] These forces of acceleration, as well as impact totals and magnitudes, are of critical value when looking for HIEs that do not result in a concussion.

The Effects of Repeated Sub-Concussive Impacts on Reaction Time Across a Football Season

Introduction

A concussion is defined as a traumatically induced transient disturbance of brain function that involves a complex pathophysiological process.[1] This injury is often caused by a traumatic event or a direct blow to the head.[2] Concussions are a common injury occurring in sports, recreational activities, and activities of daily living.[3] Concussions are so common that an estimated 3.8 million occur in the United States every year[2], however the true number could be higher due to underreporting and lack of symptom awareness. Some common symptoms of a concussion include headache, dizziness, fatigue, difficulty concentrating, sensitivity to light or noise, and memory problems[2], with headaches and dizziness being reported the most.[4] Signs of a concussion that can be seen externally include poor physical coordination, disorientation, amnesia, change in personality, decreased reaction time (RT), and loss of consciousness.[4,5]

Concussions reported in sport vary from those seen in the general population. Specifically, they are prevalent in a younger population, affecting children and adolescence at a higher rate than other activities.[1,5,21] They also frequently result from low-velocity impacts, which are common in collision sports such as American football.[4] In fact, concussions account for 7.5% of total reported American football related injuries.[6] This high prevalence in a specific population has led to the development of a distinct term known as sport related concussion (SRC).

The low velocity impacts associated with an SRC are often repetitive in nature and are more likely to present with symptoms when exposures are cumulative.[7] Repetitive head impacts that present with no signs or symptoms have been suggested as a possible cause for chronic brain injury, such as chronic traumatic encephalopathy and Alzheimer's disease.[8-10] Known more specifically as sub concussive forces: these impacts are important to account for due to the potential links to chronic adaptations in the brain. Currently, the literature shows a lack of understanding of how sub concussive forces affect objective, measurable signs of a concussion.

One of the most sensitive indicators of a decrease in neurocognitive functioning is a prolonged reaction time.[10] Specifically, reaction time has been shown to have a sensitivity of 79% and a specificity of 61% to detecting a neurocognitive decline.[7] Therefore, RT is included in many baseline concussion testing platforms commonly seen in sport, including ImPACT©, Sway Medical©, and C3 Logix©. Neurocognitive assessments such as these also consistently show deficits following an SRC that last 1 to 2 weeks, sometimes up to 6 months.[17] However, the contribution of repetitive sub concussive impacts, such as those commonly seen in American football, towards reaction time impairment has not been adequately studied. Therefore, the purpose of this study is to analyze the relationship between sub concussive forces and reaction time in collegiate football players. Due to the high sensitivity of RT to detect changes in neurocognitive functioning, as well as its important role in sport, RT will serve as the dependent variable of this study.

<u>Specific Measurable Aims and Hypotheses</u>

1. To compare the total number of HIEs between impact groups (99%, 95%, <95%).

   Hypothesis 1a: We predict that there will be more HIEs in the <95% threshold compared to the 99% and 95% thresholds.

2. To compare pre- and post-season simple reaction time measurements for everyone.

   Hypothesis 2a: We predict that post-season reaction time measurements will be higher compared to pre-season measurements indicating a reduction in reaction time performance ability.

3. To compare pre- and post-season impulse control measurements for everyone.

   Hypothesis 3a: We predict that post-season impulse control measurements will be higher compared to pre-season measurements indicating a reduction in impulse control ability over the course of the season.

4. To compare pre-season and post-season Inspection Time measurements for everyone.

   Hypothesis 4a: We predict that post-season inspection time measurements will be higher compared to pre-season measures indicating a reduction in inspection time ability over the course of the season.

5. To compare pre-season and post-season simple reaction time scores with individual total number of HIEs.

   Hypothesis 5a: We predict that individuals with a higher total number of HIEs will have a larger increase in simple reaction time scores over the course of the season.

6. To compare pre-season and post-season impulse control measures with individual total number of HIEs.

Hypothesis 6a: We predict that individuals with a higher total number of HIEs will have a larger increase in impulse control scores over the course of the season.

7. To compare pre-season and post-season inspection time measurements with individual total number of HIEs.

   Hypothesis 7a: We predict that individuals with a higher total number of HIEs will have a larger increase in inspection time over the course of the season.

Methods

Experimental Design

The design of this study was a prospective cohort study. Data collection occurred throughout the 2022 football pre-season and regular season, during both practices and games. The population of study included the Ursinus College football team. The independent variable was the number of head impact exposures (HIEs) sustained by each participant in the 95%, 99%, and <95% threshold categories. This allowed categorization of HIE data by frequency and magnitude. The dependent variables were the change in participant reaction time measurements to include the simple reaction time (SRT), impulse control (IC), and inspection time (IT), as these are the 3 measures of reaction time that Sway© collects. Sway©, a computerized cognitive assessment application for smart devices, is the current baseline concussion testing software used at Ursinus College. This neurocognitive test records important data when evaluating patients for suspected concussions, including a symptom checklist and balance, reaction time, and memory assessments. The 3 specific cognitive measures utilized in this study were SRT, IC, and IT, which are the 3 measures Sway© collects to assess RT. The Sway© test was performed by participants at the beginning of the pre-season and again within a week of the conclusion of the season. The independent variable was the number of HIEs throughout the season, which was recorded with helmet accelerometer technology (Riddell Insite©) that was monitored during and after each practice session. The impact groups of 95% and 99% were pre-determined using the Insite© software and delineate linear and rotational acceleration, location of impact, and duration of impact. The <95% group will measure head impact exposure in the form of linear acceleration and location of impact only, therefore duration of impact and rotational acceleration will not be measured for hits below the 95% threshold.

Participants

A total of 25 National Collegiate Athletic Association (NCAA) Division III football players were recruited from Ursinus College (Collegeville, PA). Determination of participants was based on player position and level of play, and priority will be given to players based on expected play time. Player positions included defensive and offensive lineman, running backs, quarterbacks, wide receivers, defensive backs, tight ends, and linebackers. We used the following grouping for subject analysis to include offensive and defensive linemen positions as the lineman group (LM) and all other skill positions as the backs groups (BKs). All recruited subjects wore the Riddell SpeedFlex© helmet equipped with accelerometer technology. Before obtaining informed consent, participants were educated on the procedures of the study and their role as subjects. This was done through an email sent during the season and a meeting with the team after practice. West Chester University Institutional Review Board of Human Subjects approved this study.

Exclusion Criteria

Subjects were excluded from the study results if their baseline measurements for SRT, IC, or IT on Sway© showed the trials were inconsistent and the average was well outside of normative values. Sway© also ranks baseline assessments by percentiles, therefore any value that falls into the lowest 10% of data within that population, or Very Low rank, will be excluded from the results. In addition, any participant who wore a helmet that did not record any impacts throughout the season will be excluded from the results, as total HIEs is the independent variable of the study.

Instrumentation Procedures

Helmet Accelerometer Technology

The Riddell InSite© technology consists of an online software that works cohesively with helmet accelerometers to record data at a constant rate while the helmet is being worn. This software is based on the Riddell sideline response system (SRS) (Riddell, Chicago, IL). The linear accelerometers record an on-field history of head impacts and location of impacts, transferring that data to the Insite© software. Insite© also works as a sideline alert system; handheld devices can be used on the sidelines to alert athletic trainers of significant single impact exposures (a 99% hit) or an accumulation of multiple impact exposures (a 95% hit) for those with the accelerometers installed into their helmets. These thresholds are determined by a pre-calculated algorithm (Principal Component Score (PCS) : $PCS=10\square((0.4718\square sGSI+0.4742\square sHIC+0.4336\square sLIN+0.2164\square sROT)+2))$ that considers linear acceleration, rotational acceleration, duration of impact, and location of impact.[14] Insite©

also records HIEs that are below a 95% hit, separating them based on magnitude (g-force) into categories of low, medium, and high magnitude.

If a 99% hit occurs and alerts the handheld monitor, it is a recognized protocol that the athletic trainer or student must evaluate that participant who sustained the 99% hit for a potential SRC. The athletic trainer will assess if the participant is experiencing any signs or symptoms of an SRC, and if potential injury is suspected the Ursinus College concussion management plan will be activated. When a 95% alert occurs, it signifies that the participant has sustained multiple hits throughout a 7-day period that surpasses the pre-determined threshold. The same protocol will occur for a 95% hit as with a 99% threshold hit.

The accelerometer technology will be installed within each Riddell Speedflex© helmet prior to the first day of contact practice. All helmets used in this study will be certified by the National Operating Committee on Standards for Athletic Equipment (NOCSAE) prior to the beginning of pre-season. Ursinus College athletic trainers, along with equipment managers will fit each subject with the proper helmet size prior to the start of pre-season practices. Proper fitting will be based on guidelines provided by Riddell©. Using a Wi-Fi connection, the handheld devices will “check in” each helmet with an installed accelerometer daily at practices or games. If a player that is on the field does not appear to “check in” on the handheld sensor, their helmet will be assessed to see if it needs to be reconnected or If batteries need to be replaced. In the event of needing batteries, they will be replaced by either the athletic trainers or the equipment managers during or at the conclusion of practice. Extra batteries will be stored before the season begins to limit the amount of HIES not being recorded. At the end of each event, the devices can be connected to a computer or laptop to upload HIE data directly to the online software, called the Insite© Training Tool (ITT) where each participant's data will be displayed.

Sway© Technology

Sway© is mobile application for smart devices that offers an interpretation of both cognitive and balance capabilities based on responses to a variety of tests. Sway© has been demonstrated to be a validated and reliable tool across various operating platforms.[15] In addition, when compared to ImPACT©, Sway© was shown to be a reliable measure of reaction time.[15] As a balance tool, Sway© is used to assess an individual's postural sway as an indicator of balance. This balance technology uses motion sensors built into mobile devices such as phones and tablets.

Sway© also functions as a cognitive assessment. The technology measure's cognitive ability through reaction time, impulse control, inspection time and memory. For this study the first three measures will be included in our analysis due to their connection to reaction time. Simple reaction time (SRT) is a measure of visual processing and neuromuscular function. With Sway©, this is assessed by the individual holding their smartphone horizontally. The phone displays one solid color on the screen, and when the color changes, the user must move their phone as a reaction to the stimulus. Impulse control (IC) is the ability of an individual to quickly process information and initiate the correct response, be it action or inaction. This is assessed through a timed response to "go" trials and "no-go" trials. Inspection time (IT) is the shortest amount of time required to visually identify a stimulus. This includes processing speed and assessing the ability to identify the same stimulus at different time intervals.

All participants in the study completed all the components of the Sway© testing prior to the start of contact practice. This was done in conjunction with the Ursinus College football team's pre-participation exam done at the start of the 2022 season. This assessment was completed in the Floy Lewis Bakes Center fieldhouse located on campus. Individual stations were set up with instructions on how to complete the Sway©. Stations were organized with space in between locations to avoid test interference. Subjects were monitored during this time, to ensure instructions were followed. Testing began with entering basic demographic information such as age, height, weight, and sex, as well as a concussion symptom checklist, broken into physical, emotional, cognitive, and sleep arousal categories. The Sway© test and all its components took participants around 20 to 25 minutes for subjects to complete. The test included multiple trials of all tests performed, and generates a consistency ranking of either low, moderate, or high. This data allowed the tester to assess the accuracy of the results. If a participant records low consistency throughout the test, retesting the individual should be considered before the start of the following practice. Data from Sway© will be exported to an Excel file. The same Sway© test was given within a week after the season has concluded. Pre-season and post season data will be analyzed for change over the season’s duration.

<u>Statistical Analysis</u>

For this study, the IBM Statistical Package for the Social Sciences (SPSS) version 24 was the data analysis software used. Descriptive statistics were performed for patient demographics and to determine the change in reaction time throughout the season by subtracting the pre-season values from the post-season values to provide ΔSRT, ΔIC, and ΔIT. A negative number will indicate that the score improved. To determine if there were differences from pre to post, dependent t-tests were performed for SRT, IC, and IT. To compare the relationship between the total number of HIEs in each subject and the change in reaction time scores, Pearson's correlations will be performed between Total HIEs and ΔSRT, ΔIC, and ΔIT. Correlations will also be performed between the number of HIEs in each of the LHIE, MHIE, HHIE, 95%, and 99% threshold categories against the ΔSRT, ΔIC, and ΔIT. An apriori of $p<0.05$ was set as the level of significance for all tests.

Results

The descriptive demographic data for all subjects can be found in Table 1. The average age for all 25 study participants was 20.32±1.22 years. The average weight of the participants was 96.89±21.42kgs and average height was 181.05±6.12cm. Breaking down the group by positions, there were 5 offensive linemen (OL), 5 wide receivers (WR), 3 running backs (RB), and 1 quarterback (QB) on the offensive side. On the defensive side of the field, there were 4 defensive linemen (DL), 3 cornerbacks (CB), 3 linebackers (LB), and 1 free safety (FS). This resulted in 9 Linemen (LM) and 16 backs (BK) overall. The total HIE data per subject is found in Table 2, and the average breakdown by positional group is found in Table 3. The individual RT, IC, and IT for preseason and postseason are found in Table 4, and the correlations between the change in RT, IC, and IT and HIE categories is found in Table 5.

<u>HIE Data Comparisons</u>

Descriptive statistics were run independently on the LM and BK groups and can be found in Table 3. On average, subjects in the LM group recorded more total HIEs (304.67±241.09) than those in the BKs group (195.81±114.56). Linemen also recorded a higher average for Low HIEs (265.67±211.88) when compared to BKS (160.63±100.51). However, this is only anecdotal as the differences were not statistically significant in either THIE ($p=.237$) or LHIE ($p=.194$)

Independent t-tests were performed to examine for differences in HIE data between subject groups (LM vs. BKS). There were no statistically significant differences between the LM and BKS groups when looking at HIE categories. This included the MHIE for LM (37.67±32.94) compared to the BKs (33.18±22.75) not being significantly different (p=.752). The same was true for HHIE data between LM (1.33±1.50) and BKS (2.25±2.14), where BKS received more HHIEs on average. However, this difference was not statistically significant (p=.136).

Sway© Reaction Time Data

Dependent t-tests were conducted to examine the differences in RT, IC, and IT scores between baseline (preseason) and post-season for each subset. The results revealed no significant difference (p=0.862) between RTPre (232.82±38.06) when compared to RTPost (231.52±21.45). No significant difference (p=.954) was found when comparing IC measures from preseason (336.83±61.15) to postseason (336.03±39.73). Dependent t-test results showed no significant difference (p=.087) when preseason IT (40.97±23.95) was compared to postseason IT (31.9±14.22).

To determine if HIE data impacted reaction time measures from baseline (BL) to post-season, correlations were conducted between each of the reaction time measures recorded (RT, IC, and IT) and each of the HIE classifications (Low, Med, High, Total, 99%,95%). The complete results for these correlations can be found in Table 4. There was a significant positive correlation (p=0.036, r=0.42) between MHIE and ΔRT. There was a significant negative correlation (p=.047, r=-.400) between ΔIT and LHIE. A significant negative correlation (p=.024, r=-.450) was found between ΔIT and MHIEs recorded. Correlations were run between THIEs and ΔIT, which resulted in a significant negative correlation (p=.036, r=-.422).

Discussion

High collision sports, such as American Football, have been shown in the literature to expose athletes to repetitive HIEs.[16-19,5] American football has also been shown to have the highest incidence of SRCs.[20] More recent evidence suggests an accumulation of SRCs, including the sub concussive HIE impacts that do not produce symptoms of a concussion may be linked to the development of long-term neurocognitive degeneration.[10,16,21-23] Reaction time measures may be sensitive to these changes at the neurocognitive level.[24-26] The purpose of this study was to analyze the relationship between sub concussive impacts and reaction time in collegiate football players across a football season.

A total of 29 subjects participated in this season long observational study. The player positions allocated for this study were OL, DL, QB, RB, WR, LB, TE, FS, and P/K. These were further categorized into either LM or BK groups for data processing. These groups were decided as LM, comprised of OL and DL players because this group has demonstrated a higher accumulation of HIEs with offensive linemen receiving up to 75% of total team impacts.[27,28] There is consistent evidence to support positional averages ranging from 417-871 HIEs across a collegiate season.[33,42,44,45] This study was able to replicate these averages and will be further remarked on below. The seasonal averages reported in the literature[33,42,44,45] also provided support for the exclusion of 2 participants, as their helmet accelerometers recorded no HIE data for the entire season. As the independent variable of this study, HIE impacts were an important variable to collect, and without values for the subjects they were excluded from statistical analysis. Two additional subjects were excluded from data analysis due to their baseline reaction time measurements, as their measurements for RT, IC, and IT all were identified as “Very Low” for their age group as categorized by Sway©. The technology also flagged their trials as inconsistent, meaning they clinically would not serve as an accurate baseline. This left 25 subjects in the study for data analysis.

Throughout the 2022 football season, the 25 participating subjects recorded a total of 5875 (235.00±174.42) HIEs and ranged from 29-847 HIEs. These averages are consistent with those found in previous research.[46] Consistent with research done by Jennings,[47] we found those in the LM group (304.67±241.09) recorded more impacts than those in the BKs (195.81±114.56) group. Despite the number of HIEs, throughout the season long data collection, no SRCs were recorded among participants. This HIE data also included 22 99% single impact alerts and 28 95% multiple impact alerts but did not result in an associated SRC. These impact alerts also did not have a statistically significant impact on ΔRT (r=.304, p=.139; r=-0.88, p=.676), ΔIC (r=.205, p=.325; r=.100, p=.635), or ΔIT (r=.121, p=.565; r=-0.055, p= .795). Though no SRCs were reported in the data, there is a chance that signs and symptoms went unreported. According to Sefton[48], up to 70% of collegiate football players did not report concussions sustained during football. This is believed to be a result of lack of knowledge on concussion symptoms or fear of losing playing time.[2]

Recent evidence shows reaction time as one of the most sensitive measures of neurocognitive impairment, as it is frequently used as an assessment tool for evaluating a patient with a suspected concussion.[1,39] In addition to the examination of HIE data, our focus was to determine if there was a relationship between reaction time measurements over time and the HIEs recorded. Previous research by McAllister et al[25] showed poor ImPACT reaction time measures in subjects with a higher amount of HIEs accumulated. The authors went on to conclude there is potentially a connection between cognitive performance and an accumulation of HIEs.[40] This study set out to interpret similar findings and to utilize new technology for reaction time data collection. In our comparisons we chose to utilize the new Sway© technology for our reaction time measurement for the BL and Post neurocognitive testing of subjects. Sway© is a neurocognitive assessment that gathers data using tests taken by a user on their own smart phone via a mobile application. This meant no additional assessment tools such as computers were necessary. This makes the collection of data through Sway© easier to collect, as many individuals can test at the same time on their own devices.

Despite the previous relationship demonstrated between RT and HIE numbers, in our examination of RT, IT, and IC measures from Sway© it was found that overall scores improved when compared to their baseline measures disproving our original hypothesis (Table 4). When comparing the change in RT, IC, and IT to the different categories of HIE data, 4 statistically significant correlations were found (Table 5). Three of them are when comparing LHIE, MHIE, and THIE data specifically to IT. All 3 of these correlations analyses revealed a negative correlation (Table 5). This is interpreted to mean that as LHIE, MHIE, or THIE data increased, scores on the IT test improved. This is consistent with previous research done by Gaglias.[46] This improvement could have been a result of a learning curve associated with the repetitive nature of multiple neurocognitive assessments.[46, 49,50] However, the learning curve in the research has only been demonstrated in ImPACT testing, as no research studying long term test-retest reliability of Sway© RT measures has been conducted to this point.

Despite showing an average of improvement in RT measures across the season, almost half of the participants scored a +ΔRT value, indicating their reaction time got worse from BL to Post. Specifically, subjects 15 and 17 had decreases in all 3 reaction time measures collected. Taking a closer look at these individual subjects HIE data showed that subject 17 was tied for the most 99% impacts in the study group with 4 total alerts (Figure 1). Subject 15 recorded 2 99% impacts during the season, and this subject recorded the 3rd most HHIEs in the study group with a total of 5 (Figure 2). Another interesting subject to look at is Subject 1, who recorded 847 THIEs, and 752 of them were LHIEs. These are the highest totals in both of these categories from our study (Figure 3), and displays findings that support those in previous research showing OL positions sustaining a higher number of HIEs in a competitive season compared to other positions.[42,43] However, this individual subject showed an improvement in both RT (3.33ms) and IT (79.33ms), with a slight decrease in IC (4.83ms).

Though our study demonstrated statistically significant improvements in multiple RT measures across a season, anecdotally there were still many subjects that displayed a decrease in performance from BL. We constructed and completed this study hoping to objectively capture subtle changes that may be indicative of long-term neurocognitive changes such as CTE and Alzheimer’s disease. These diseases currently have no way of being detected before symptoms onset, so the value of a way to detect these changes earlier and intervene is immeasurable. Addressing and identifying limitations of this study would be prudent to develop a continuation of this work that may allow for more comprehensive and definitive conclusions.

We are careful to address limitations that may have impacted on our findings. One limitation is potentially the testing environment during data collection for BL. This was completed during the PPE process in the gymnasium on the other side of a curtain from where other students were completing their PPE. This could have served as an auditory distraction for participants, which could have skewed their baseline data. If the baseline was skewed, the results at the end of the season could show some athletes with improvements that may not have been exaggerated. Overall, future testing should control the environment for BL and Post testing to achieve more accurate results. Another limitation is that Sway© defines IT deficits as a change of >+34ms. Therefore, it may be inaccurate to conclude that the participants improved in the categories where a positive correlation was found (Table 5). Another limitation is the small sample size making it difficult to make global inferences. Lastly, a limitation was the technology failure that occurred in 2 subjects. It is hard to conclude how their data would have contributed to the findings of the study, and future research should monitor impacts on Riddell Insite Training to catch and address these issues earlier.

Conclusion

The purpose of this observational cohort study was to examine the relationship between sub-concussive impacts and reaction time in NCAA collegiate Division III football players across a football season. We were able to demonstrate trends in HIE data consistent with previous research, including trends of sub-concussive impacts occurring at a higher prevalence than concussive impacts. We were also able to demonstrate changes in multiple reaction time measures over a prolonged period. However, further research is needed to validate the effects of repetitive HIEs on reaction time measurements in collision sport athletes such as American football. This study contributes findings towards the ongoing research of HIEs, sub concussive impacts, and long-term neurodegeneration in athletes.

Appendix A: Table 1. Subject Demographics

Subject	Position	Age (yr.)	Height (cm)	Weight (kg)	Concussion Hx	Years of Collegiate FB experience
1	LM	21.00	175.26	104.32	no	4
2	BK	20.00	175.26	79.38	yes	2
3	BK	19.00	185.42	81.65	yes	2
4	BK	22.00	170.18	68.04	yes	5
5	BK	20.00	182.88	102.06	no	2
6	BK	20.00	177.8	107.96	yes	2
7	BK	19.00	185.42	81.65	yes	2
8	BK	20.00	180.34	74.84	no	3
9	BK	22.00	177.8	77.11	no	4
10	BK	21.00	175.26	74.84	no	4
11	BK	19.00	185.42	83.46	no	2
12	LM	20.00	190.5	131.54	no	3
13	BK	20.00	175.26	105.69	yes	3
14	LM	22.00	187.96	117.93	yes	4
15	BK	22.00	180.34	99.79	no	4
16	BK	19.00	170.18	81.65	no	2
17	LM	21.00	182.88	86.18	no	4
18	LM	19.00	182.88	113.40	no	1
19	LM	20.00	182.88	108.86	no	3
20	LM	19.00	190.5	117.93	no	2

21	LM	22.00	190.5	151.95	yes	4
22	LM	18.00	180.34	127.01	yes	1
23	BK	21.00	180.32	88.45	no	3
24	BK	22.00	187.96	81.65	yes	5
25	BK	20.00	172.72	74.84	yes	3
	Mean	20.32	181.05	96.89		2.96
	SD	1.22	6.12	21.42		1.14

Appendix B**:** Table 2. **Overall HIEs and Threshold Data for the 2023 Football Season**

Subject	Total HIEs	LHIEs	MHIEs	HHIEs	99%	95%
1	847	752	94	1	0	2
2	171	138	31	2	0	0
3	30	26	3	1	0	0
4	417	380	35	1	1	8
5	226	191	32	3	1	0
6	326	233	93	6	1	0
7	29	29	0	0	0	0
8	297	275	21	1	1	3
9	110	96	12	2	1	0
10	296	231	58	6	4	6
11	203	158	40	5	1	0
12	297	275	22	0	0	2
13	156	114	51	0	0	0
14	330	264	64	2	0	5
15	347	298	44	5	2	0
16	122	92	30	0	0	0
17	446	362	80	4	4	0
18	48	39	9	0	1	0
19	303	280	23	0	2	0
20	258	227	28	3	1	2
21	149	132	15	2	0	0
22	64	60	4	0	0	0
23	119	83	36	0	0	0
24	90	76	12	2	1	0
25	185	150	33	2	1	0
Totals	5875	4961	870	48	22	28
Mean±SD	235.00±174.42	198.44±154.68	34.8±26.27	1.92±1.96	0.88±1.13	1.12±2.19

Appendix C: Table 3. HIE average data by position group

	THIE	LHIE	MHIE	HHIE	99%	95%
LM	304.67±241.09	265.67±211.88	37.67±32.94	1.33±1.50	.89±1.36	1.22±1.72
BKS	195.81±114.56	160.63±100.51	33.18±22.75	2.25±2.14	.75±1.00	1.06±2.426

Appendix D**:** Table 4. Average RT, IC and IT data and change over the Football Season

	Preseason(ms)	Post season(ms)	Δ(ms)
RT	232.82	231.52	-1.30
IC	336.83	336.04	-.79
IT	40.97	31.91	-9.06

Appendix E: Table 5. Correlations between HIE data and ΔSRT, ΔIC, and ΔIT

	LHIE	MHIE	HHIE	THIE	99%	95%
ΔRT	r=.146	r=.420*	r=.332	r=.195	r=.304	r=-0.88
	p=.485	p=.036	p=.105	p=.351	p=.139	p=.676
ΔIC	r=.324	r=.373	r=.257	r=.344	r=.205	r=.100
	p=.114	p=.066	p=.214	p=.092	p=.325	p=.635
ΔIT	r=-.400*	r=-.450*	r=-.119	r=-.422*	r=.121	r=-0.055
	p=.047	p=.024	p=.572	p=.036	p=.565	p= .795

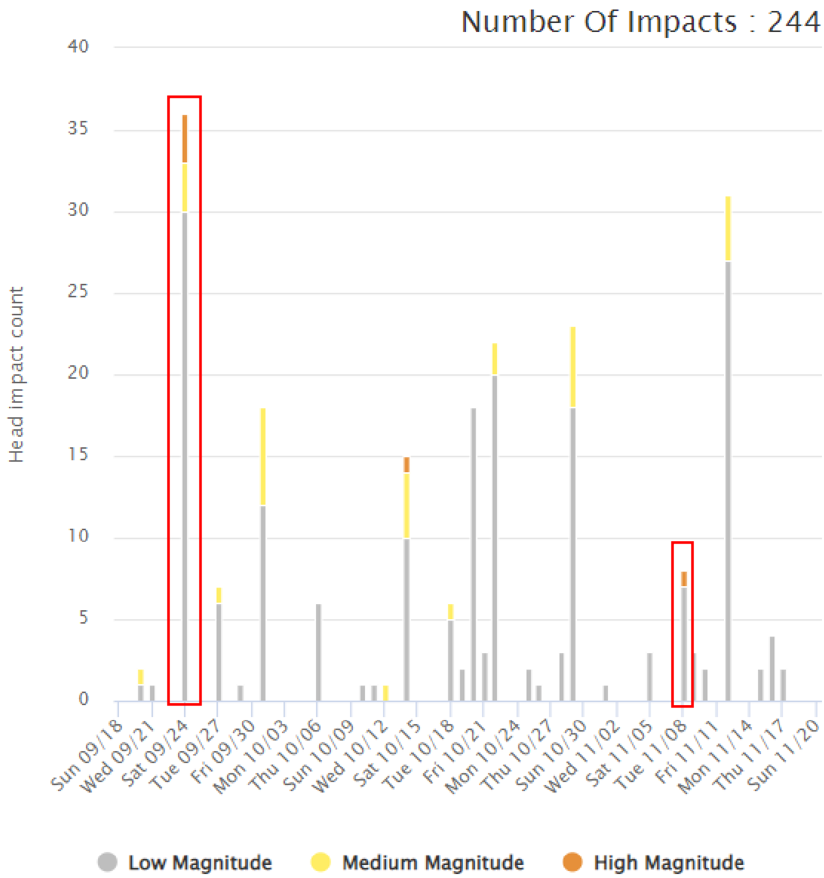
*Shows an R value statistically significance at p≤0.05 level.

Appendix F: Figure 1. **Subject 17 99% impacts**

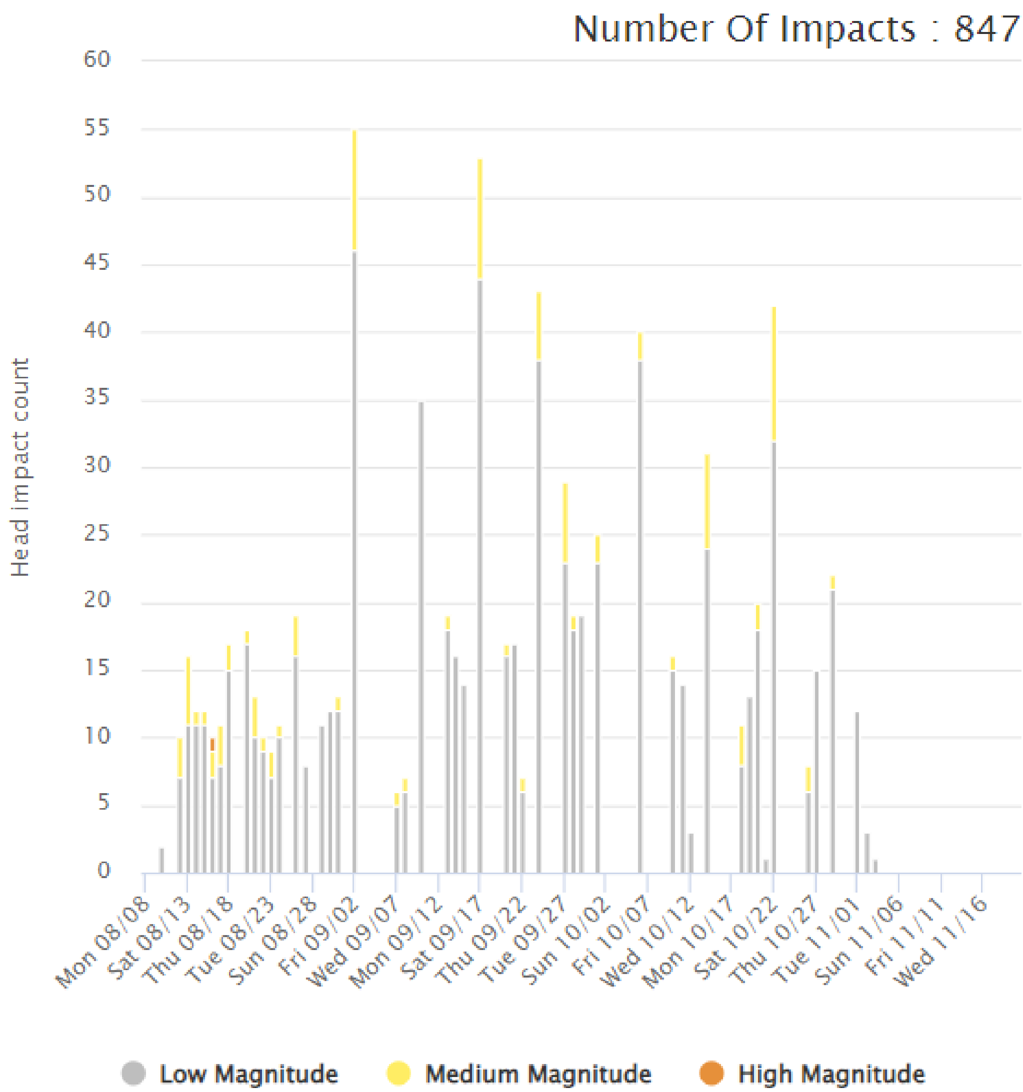
Alerts

Date	Alert	Alert Location
Wed 08/10 09:09 AM	Single	Right
Mon 08/15 10:38 AM	Single	Front
Tue 09/20 06:32 PM	Single	Front
Tue 10/18 03:59 PM	Single	Front

Appendix G:Figure 2. Subject 15 HHIE data



Appendix H: Figure 3. Subject 1 Total HIE Data



Appendix I: Letter of Approval from West Chester Institutional Review Board

WCU
WEST CHESTER
UNIVERSITY

Office of Research and Sponsored Programs | West Chester University | Ehinger Annex
West Chester, PA 19383 | 610-436-3557 | www.wcupa.edu

Sep 6, 2022 4:09:33 PM EDT

To: Theodore Mostellar
Sports Medicine Department

Re: Expedited Review - Initial - IRB-FY2022-384 The Effects of Repeated Sub-Concussive Impacts on Reaction Time Across a Football Season

Dear Theodore Mostellar:

Thank you for your submitted application to the WCUPA Institutional Review Board. Since it was deemed expedited, it was required that two reviewers evaluated the submission. We have had the opportunity to review your application and have rendered the decision below for The Effects of Repeated Sub-Concussive Impacts on Reaction Time Across a Football Season.

Decision: Approved

Selected Category: 4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.)

Sincerely,
WCUPA Institutional Review Board

IORG#: IORG0004242
IRB#: IRB00005030
FWA#: FWA00014155

Appendix J: Informed Consent Form

Project Title: The Effects of Repeated Sub-Concussive Impacts on Reaction Time Across a Football Season

Investigator(s): Theodore Mostellar; Kathrine Morrison

Project Overview:

Participation in this research project is voluntary and is being done by Theodore Mostellar as part of his Master's Thesis to analyze the relationship between sub-concussive forces and reaction time in collegiate football players across a football season. Your participation will take the duration of the football season (10 and ½ weeks). The Sway medical test was already taken as part of your baseline concussion testing here at Ursinus, and participation would require a second test at the end of the season, taking roughly 25 minutes to complete.

Participants have been assigned a Ridell Speedflex © helmet with InSite technology inside. The participant will then take their Sway concussion baseline testing, same as in previous seasons. A participant will then be brought in at the conclusion of the season to complete the Sway testing again. Participation in this research is expected to be greatly beneficial. The data collected would be used to give subjects a better understanding the head impact exposures they experience across a season. This includes using it as an educational tool to improve tackling technique based on the location, frequency, and magnitude of impacts. The benefits to society include improvement of rehabilitation process, symptom management, and player safety and education. There are no anticipated risks to participants in this study.

The research project is being done by Theodore Mostellar as part of his Master's Thesis to analyze the relationship between sub concussive forces and reaction time in collegiate football players across a football season. If you would like to take part, West Chester University requires that you agree and sign this consent form.

You may ask Theodore Mostellar any questions to help you understand this study. If you don't want to be a part of this study, it won't affect any care you may receive from Ursinus College. If you choose to be a part of this study, you have the right to change your mind and stop being a part of the study at any time.

1. **What is the purpose of this study?**
   - analyze the relationship between sub concussive forces and reaction time in collegiate football players across a football season.
2. **If you decide to be a part of this study, you will be asked to do the following:**
   - Participant will be assigned a Ridell Speedflex © helmet with InSite technology inside
   - Participant will then take their Sway concussion baseline testing, same as in previous seasons
   - participant will then be brought in at the conclusion of the season to complete the Sway testing again.
   - This study will take 2 tests (25 minutes each) of your time.

3. **Are there any experimental medical treatments?**
    - No
4. **Is there any risk to me?**
    - There are no anticipated risks to this study. Data stored safely on a password protected computer and will be coded to reduce the risk of the information becoming public.
5. **Is there any benefit to me?**
    - Benefits to you may include: The data collected would be used to give subjects a better understanding the head impact exposures they experience across a season. This includes using it as an educational tool to improve tackling technique based on the location, frequency, and magnitude of impacts.
    - Other benefits may include: The benefits to society include improvement of rehabilitation process, symptom management, and player safety and education.
6. **How will you protect my privacy?**
    - The session will **not** be recorded.
    - Your records will be private. Only Theodore Mostellar, Kathrine Morrison, and the IRB will have access to your name and responses.
    - Your name will **not** be used in any reports.
    - Records will be stored:
        - Password Protected File/Computer
    - Records will be destroyed After manuscript development, but no less than three years
7. **Do I get paid to take part in this study?**
    - No
8. **Who do I contact in case of research related injury?**
    - For any questions with this study, contact:
        - **Primary Investigator:** Theodore Mostellar at 570-872-7224 or tm983231@wcupa.edu
        - **Faculty Sponsor:** Kathrine Morrison at 610-436-3293 or kmorrison@wcupa.edu
9. **What will you do with my Identifiable Information?**
    - Your information will not be used or distributed for future research studies. Data collected will only be used for this study. If data is to be used in future studies, participants will be notified.

For any questions about your rights in this research study, contact the ORSP at 610-436-3557.

I, ___________________________________ (your name), have read this form and I understand the statements in this form. I know that if I am uncomfortable with this study, I can stop at any time. I know that it is not possible to know all possible risks in a study, and I think that reasonable safety measures have been taken to decrease any risk.

____

Subject/Participant Signature Date:_________________

____

Witness Signature Date:_________________

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