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Head Linear and Rotational Forces and The Relationship To Sub-Concussive Hits In The Professional Lacrosse Player

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ABSTRACT

Objective: *Concussions have been extensively researched, defined as a mild traumatic brain injury (mTBI) resulting in symptoms including headaches, dizziness, decreased attention, etc. Sub-concussion, although closely related, has only been a recent focus of research; increasing concern is developing regarding cumulative effects of mTBIs that may have equally or more severe consequences.*

Design: *This observational cohort study assessed summative effects of impacts with an emphasis on sub-concussive hits in Professional Men's Lacrosse.*

Setting and Participants: *GForce tracker sensors were placed in 26 male players' helmets on the one Major League Lacrosse Team prior to games of the 2015 season. Data was collected during solely during game time play.*

Assessment of Risk Factors: *Because of the unknown effects of repetitive sub-concussive hits, head exposure in contact sports is proven to have long term cognitive, emotional, and physical effects. As professional athletes, participants were aware of this risk.*

Main Outcome Measures: *The sensors registered forces greater than 20g, with simultaneous transfer to a database for post-season analysis. The focus of data was average linear acceleration and number of hits with respect to impact location and player position.*

Results: *Number and force of impacts differ dependent on player position.*

Conclusions: *Midfielder players were subject to the greatest number of impacts in a game setting. Further examination of the effects of rotational and linear accelerations of sub-concussive hits in Professional Lacrosse players is indicated to define a dangerous number of hits as well as a minimum level of impact that is detrimental to the athlete's well-being.*

Keywords: Concussion, Sub-Concussion, Professional Lacrosse, Rotational Acceleration, Linear Acceleration

INTRODUCTION

A concussion is a mild traumatic brain injury (mTBI) resulting from a direct or indirect impact to the head, leading to functional deficits such as confusion, dizziness, nausea, vomiting, sensitivity to light and sound, decreased attention, headaches, etc., with a potential for loss of consciousness. Recent research has recognized severe long-term effects of concussions, including Chronic Traumatic Encephalopathy (CTE), Alzheimer's, and Parkinson's Disease [1-4]. Incidence of such co-morbidities has pushed researchers to investigate sub-concussive hits.

A sub-concussion is defined as "mTBI that does not produce the characteristic neurological signs and symptoms and does not lead to concussion diagnosis [5]." Multiple, concurrent sub-concussive hits have the potential to impact tissues in the brain, and therefore function [1-4]. Exposures to these impacts may lead to the above diagnoses; due to post-mortem imaging for diseases like CTE, extensive brain damage is not discovered during an athlete's career [3]. CTE is a cornerstone diagnosis of athletes who have sustained many sub-concussive hits. Baugh et al determined in a

2012 study that all patients diagnosed with CTE had the presence of mTBI, but not all individuals who suffered from head trauma had evidence of CTE. This emphasizes the importance of identification and prevention of meaningful impacts to include sub-concussive precautions. By limiting the number of forces sustained by the brain, the hope is to decrease the consequences in contact-sport athletes.

Current research lacks significant, evidence-based information of sub-concussive hits' specific to Major League Men's Lacrosse. Lacrosse is one of the fastest growing sports in the United States, and concussion is one of the top three most common injuries reported during athletic play [6,7]. Linear and rotational acceleration are the primary risk factors for concussion due to an impact to the head [8]. Concussion in lacrosse is relatively understudied compared to other sports, even though it involves repetitive hits at high speeds and great forces [6,7].

Research by Miyashita analyzed Men's College Lacrosse players at the Division I level [6]. Miyashita researched incidence of impacts in games versus practice settings, average force and number of hits by position. She concluded injury is four times more likely in a game versus practice; findings by position found the highest number of hits in midfielders, but the highest average linear acceleration in goalies [6]. It is expected that midfielders acquire more hits than other players because they cover a great amount of distance during a game and may encounter the most interactions with other players and the ball [9]. The issue with research into sub-concussive hits is difficult due to the multitude of variables including, individual factors, gender, sport/event, position, duration of play, and collision type, and others [10-15]. Specifically, a factor that has been studied is historical head impact exposure (HIE), which suggests a correlation with damaging effects of multiple previous sub-concussive hits in delayed diagnosis of concussion [16]. It becomes increasingly difficult to account for and compare subjects, and the specific threshold to differentiate sub-concussive versus concussive hits. As more research is conducted, the goal is to identify common denominators to take action against such injuries.

This study aims to provide health care professionals, coaches and players with information regarding the magnitude of sub-concussive hits to be identified. Opening up this discussion would greatly increase awareness regarding the significant long term effects of such hits. By implementing initiatives to decrease exposure in contact sports there is a potential to decrease harm on the brain, including co-morbidities [17-19]. It has been shown through multiple studies that athletes underreport symptoms, including when it is concussion-related. Symptoms alone are not enough to diagnose a concussion, and proper management is key in decreasing long-term adverse effects [7]. A few studies have examined linear and rotational accelerations of the head, yet a defined significant level has not been classified [17-19]. Additional research needs to be completed to better understand the forces and how varying magnitudes directly impact the health of brain tissue. Though a threshold for mTBI has not been definitively identified, understanding the biomechanics of such an injury is critical to the advancement of this area of study [20]. Specifically, this study serves to contribute to defining a baseline of magnitudes and forces with potential harmful consequences.

I hypothesized that the highest number of hits in midfielder players versus other positional players. This study hoped to provide information regarding the danger of cumulative effects of hits to maintain safety and minimize harm. The purpose of this study was to examine the effects of rotational and linear accelerations of sub-concussive hits in Major League Lacrosse players.

METHODS

The study consisted of an observational cohort study research design. I observed a single Major League Lacrosse (MLL) team over the 2015 season and did not provide a direct intervention. Data collected during the study was not used for interventional or diagnostic purposes because we have yet to define a meaningful concussive or sub-concussive force using the GForce Tracker sensors. Data collected was used strictly for observational purposes.

Because of the limited research into the sport generally, and specifically Professional Men's Lacrosse, it is difficult at this time to assume the findings of this study can be accepted with respect to athletes of different ages, level of play, or sport type. The lack of a single report of a diagnosed symptomatic concussion throughout the season with the highest and most commonly occurring impact forces ranging between 20-50g allows us to maintain the purpose of the study in examining cumulative sub-concussive impacts. But in line with Forbes et al. in the research of American Football at the high school and collegiate levels, data collected on player position, location of hit, number of impacts, etc. cannot alone define a "significant" force at which a concussion will occur due to a variety of other individual factors [13].

Participants

Twenty-six professional men's lacrosse players volunteered. All subjects were members of one Major League Lacrosse Team. Considering how concussions occur, there are a multitude of factors that cannot be controlled including height, weight, age, body type, and position played. However, statistics to were needed and included in this study. The average height was 71.9 inches with a standard deviation (SD) of 1.98 inches. The average weight was 190.9 pounds with a SD of 15.03 pounds. The average age was 24.38 years old with a SD of 1.98 years.

Inclusion criteria included being on the active roster of the this Major League Lacrosse Team during the 2015 season and being active for that week's game. Exclusionary criteria included any player not using a Cascade Pro 7 team issued lacrosse helmet. Data was collected by the team certified athletic trainer throughout the 2015 season throughout 14 games. 20 sensors and the accompanying software were donated to the team by GForce Tracker Company. Each sensor was assigned to a specific player prior to every game. Immediately following each game, data was collected and downloaded into the player's individual GForce Tracker profile.

Instrumentation

The sensors were able to measure linear and angular acceleration and were worn during games. Each sensor was set to acknowledge and record any linear and angular acceleration impact over 20g. Sensors identified significant impacts experienced by the player and then data was sent to the database and a tablet instantly. After each game, data was downloaded using the table via the cloud to GForce Tracker software.

Procedures

Each helmet was prepared by placing a small piece of velcro (50mm x 25mm) on the inside crown on the lacrosse helmet as well as on the bottom (flat) side of the GForce Tracker sensor (50mm x 28mm x 14mm). The sensor was then mounted inside the helmet with the USB connector facing the front of the helmet. Each sensor had to be calibrated and assigned prior to first use. With the GForce Tracker sensor mounted to the velcro in the helmet, it was plugged into a computer using a USB cable; this caused the GForce Tracker to automatically awaken. There were then three positions used to calibrate the sensor. With position one, the helmet was placed flat on a table with the facemask facing towards the person calibrating. The "calibrate device" button was then pressed in this position. With position two, we placed the helmet on its left side on a flat table and calibrated. The final step, position three, called for the helmet to be positioned on its posterior side on a flat table and calibrated.

Statistical Analysis

Descriptive statistics were computed for GForce, Head Impact Criteria (HIC), Gadd Severity Index (GSI) scores, and frequency distribution for linear acceleration. HIC scores are based on a one-mass model using global linear acceleration. It does not account for angular acceleration or direction [21]. Analysis of variance statistics were computed with Games-Howell post-hoc tests, because equal variances cannot be assumed, to determine if there were significant differences between player positions and impact locations with linear acceleration. All data were analyzed with SPSS (version 23; IBM Corp. Armonk, NY). Statistical significance was established a priori as $\alpha \leq 0.05$.

ETHICAL CONSIDERATIONS

This study was classified as exempt as per the Northeastern University Institutional Review Board (IRB), as the data was collected before the start of the study. Players provided consent for data collected during the 2015 season to be utilized during this study. Players were made aware that data collected would correspond with their individual profile, which would be accessed by researchers. Identifying information will not be included in any publications. All participants were volunteers and no data collected during the study was used to provide an intervention.

RESULTS

A total of 3,403 impacts to the head were recorded among all players in the 2015 season. The mean linear acceleration recorded through the GForce Tracker software was 40.94 g with a SD of 22.05. The lowest recorded force was 20.31 g, and the highest was 214.55 g. Forces were also recorded in terms of the HIC and the GSI (Table 1).

Table 1: Average linear acceleration, in g.

	N	Mean	Std. Deviation	Minimum	Maximum
gForce	3403	40.94	22.05	20.31	214.55
HIC	3403	12.37	34.96	.1	908.4
GSI	3403	32.11	71.23	2.10	1591.90

An analysis of variance indicated that the player positions differed significantly on average linear acceleration per impact, $F (4, 3398) = 6.34$, $p < 0.001$. Post hoc Games-Howell tests indicate that Face Off players experienced lower average linear accelerations per impact when compared to Goalies ($p = 0.003$) and Midfielders ($p < 0.001$). (Figure 1 and Table 2)

Figure 1. Frequency distribution for the 3,403 impacts by linear acceleration is a graphic representation of the forces recorded via the GForce Tracker software, in g.

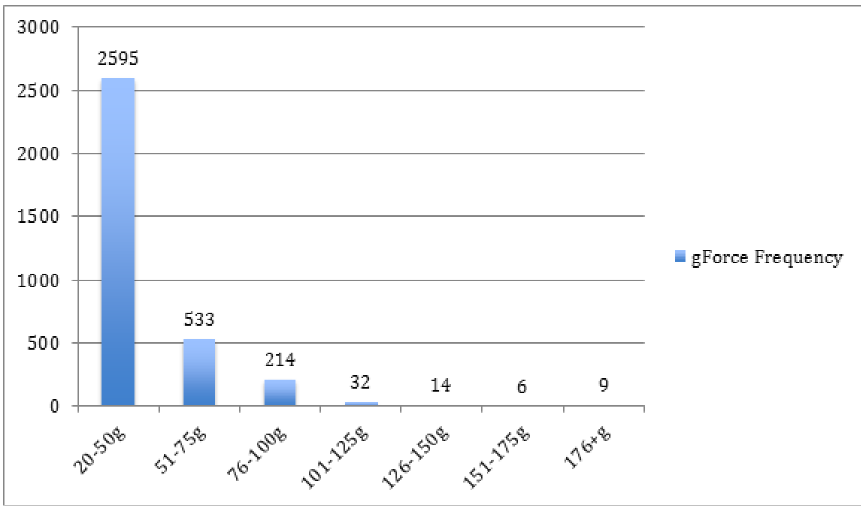

Table 2: Average linear acceleration by player position

Position	N	Mean	Std. Deviation	95% Confidence Interval	
				Low	High
Goalie	444	42.19	24.41	39.91	44.46
Face Off	481	37.00	18.32	35.36	38.64
MidFielder	1477	42.38	21.55	41.28	43.48
Attack	550	39.55	21.26	37.77	41.33
Defense	451	40.87	25.09	38.55	43.19
Total	3403	40.94	22.05	40.2	41.68

A statistically significant difference was found among the six head impact locations and average linear acceleration, $F(5, 3397) = 6.49$, $p < 0.001$. Post hoc Games-Howell tests indicated that impacts to the back of the head resulted in significantly higher average linear accelerations when compared to the top ($p = 0.05$), bottom ($p < 0.001$), and left ($p = 0.025$). Impacts to the top of the head resulted in significantly higher impact when compared to the bottom ($p = 0.033$), and impacts to the right side of the head resulted in significantly higher impact when compared to the bottom ($p = 0.003$). (Table 3)

Table 3: Average linear acceleration by impact location

Impact Location	N	Mean	Std. Deviation	95% Confidence Interval	
				Low	High
Front	444	40.48	21.64	38.46	42.50
Back	562	44.64	25.91	42.50	46.79
Top	784	40.75	22.76	39.16	42.35
Bottom	373	36.50	22.37	34.22	38.78
Right	682	41.43	16.77	40.17	42.69
Left	558	40.20	22.06	38.36	42.03
Total	3403	40.94	22.05	40.20	41.68

I found that midfielders experienced the most hits at a total of 1,477. After that, players in the attack position experienced 550 total hits, face-off players experienced 481 total hits, defensemen had a total of 451 hits, and goalies had a total of 444 hits. The face-off, midfielder, and attack positions all experienced the most frequent hits to the top of the helmet. The defense positions experienced the most frequent hits to the bottom of the helmet and goalies experienced the most frequent hits to the right side of their helmet.

DISCUSSION

Clinical Implications

Research is currently working on analyzing data in order to identify a number that is a statistically significant force. There are also no guidelines to a mandated rest period or being taken out of a game after a hit to the head. However, there is currently a lack of evidence and research regarding the long-term effects of repetitive sub-concussive hits. There is a great risk to playing contact sports and it has been proven that exposure to repetitive hits has long term cognitive, emotional, and physical consequences [1-4,22]. This topic has gained publicity lately through CTE diagnoses in NFL players. CTE is a degenerative neurologic disorder linked to concussion and sub-concussive hits with symptoms including depression, anxiety, and behavioral changes [14]. In order for contact sports to change, there needs to be a definition of a sub-concussive hit, especially because they are asymptomatic.

Strengths & Limitations

This study has several strengths. This is the first study to assess a professional sports team in regard to sub-concussive hits. Previous studies have been conducted at the collegiate level, but no other studies have involved professional lacrosse, or any other sports at the professional level. The data collection was consistent throughout one season with one roster and one certified athletic trainer. Research has been very supportive of GForce Tracker sensor use. These sensors, unlike many previous models, are placed directly in the helmet and do not require a head strap to be secured. The head straps of other models can often cause discomfort and run the risk of moving, sliding, and altering the fit of the player's helmet. The GForce Trackers not only eliminate these risks but have strong supportive evidence regarding data collection [18]. Due to the nature of the data and this study there are few limitations. The sample size was small due to the fact that data was only collected from one Major League Lacrosse team, over the course of one season. Data was only collected from games and not practices. There have also been limited amounts of research done with the G-force sensors, therefore these studies have not been able to correlate a specific force with the direct impact of a concussive or sub- concussive hit. Since there are limited amounts of data regarding this information, the force at which the sensors were set to record data and impacts is rather arbitrary. Through this study and other research currently being done, this study aims to identify and correlate meaningful forces with concussive and sub-concussive hits. Also, through data analysis allowed many conclusions to be drawn, but did not take into account how much time each player spent on the field. In lacrosse, certain players in different positions will cover more space on the field, most likely predisposing them to an increased number of impacts. For example, the average linear acceleration experienced by face off players are in fact lower than other positional players on the field. This is most likely due to the fact that they spend less time on the field than most of the other players because they are on and off the field solely for face offs. This study did not account for how much time each player was active in each game. This may have been able to further explain some of the discrepancies in data for magnitude of impacts or the number of impacts experienced by the player.

Future Research

This study aims to limit sub-concussive hits and exposure in order to decrease the negative impact of repetitive head trauma [17]. Chris Nowinski has proposed the Hit Count Initiative, similar to the Pitch Count instituted by little league baseball to prevent overuse injury of the arm in Little League baseball players [23,24]. This proposed hit count directly relates to limiting the cumulative effects of sub-concussive hits by mandating time off the field after an impact greater than 20g of force. In order for this to be a reality, there needs to be evidence behind this value, or another defined threshold for concussive and sub-concussive hits to identify meaningful impacts [23]. Other initiatives are also being advocated for. In Canada, the youth hockey leagues have identified that body checking in leagues increases the player's risk for concussion and they are further working on implementing an initiative similar to the hit count and delaying the introduction of checking until a later age [25]. This will help certified athletic trainers and coaches protect their players. However, research still needs to expand into collegiate, high school, and youth levels, as well as other sports. This study aims to initiate the conversation by proving there is a need for defining a relationship between force and sub-concussive hits. It is recommended that additional research needs to occur in order to know more on this topic and provide the correct attention to athletic exposure to sub-concussive hits.

There are already studies that provide evidence of the possible adverse effects due to multiple concussions [7,23]. However, there has not been enough research looking at the effects of multiple sub-concussive hits. This study intends for outcomes to promote further research in professional lacrosse regarding sub-concussive hits and the potential long term consequences of repeated impacts to the head. Similarly to Miyashita's research, this study supports the hypothesis that midfielders acquire more impacts in a game setting compared to all other players on the field [6]. This ties into the individuality of concussion risk, as these players have more on-field time and therefore a greater risk for cumulative damage due to repetitive sub-concussive trauma. These consequences are relatively understudied in lacrosse, compared to sports such as football and boxing, and additional study is required to implement change in MLL policies and regulations. The expected outcomes of this study are to encourage research at the collegiate, high school, and youth levels as well.

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