Title Page for Undergraduate Honors Thesis

Potential Risk Factors for Concussion in Volleyball; High-Velocity Attacks and Head Exposures

by

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Abstract

Context: There are 3.8 million concussions a year in the United States from sports and physical activity. The concussion rate in collegiate volleyball players is 5% with the majority of these occurring as a result of contact with the equipment (the ball).[4,] It has been determined that the average speed of a volleyball kill in elite-level college volleyball is 50-70 mph.[5]

Objective: This study analyzed the opportunities created during a volleyball match that could result in head impacts with the ball and lead to a concussion.

Methods: Using VolleyMetrics, a software that offers videos of volleyball matches, 48 Mid-season ACC volleyball games (20 in 2016 and 28 in 2022) were coded to record high-velocity kills, head impacts in front-row and back-row players, and occurrences when the front-row player's heads were over the net during blocking. Data were collected to answer if there were differences between 2016 and 2022 in the percentage of high-velocity attacks, the percentage of heads over the net, and the number of heads hit as well as in which rows.

Results: A Kruskal Wallis H Test through SPSS Version 29 concluded that there was not a significant difference in the percentage of high-velocity attacks and the percentage of heads over the net in 2016 and 2022. The average percentage of high-velocity attacks was 59.21%. There was an average of 250 attacks a game from the 48 games analyzed, therefore, 148 of the 250 attacks would be deemed high-velocity. This is 148 times there is an opportunity for a concussion to occur.

Conclusion: Although the difference between time periods was not significant, the incidence rates for hits to the head might explain the number of concussions that are seen in volleyball. For front-row players, the overall incidence rate of ball hits to the head was 6.8 per every 1000 exposures. There was an increase in the incidence rate of back row players hit in the

head from 1.7 per every 1000 exposures in 2016 to 4.6 per every 1000 exposures in 2022. While we are unable to determine if these impacts to the head with the ball result in concussion, the incidence of head hits is concerning as they may lead to injury.

Chapter I

Introduction

The primary mechanism of concussion is any linear or rotational biomechanical force that causes the brain tissue to deform as a response. The leading causes of concussions in all people are football, soccer, and motor vehicle accidents. Seiger et al. found that out of 170,000 total Emergency Department visits in individuals aged 19 and younger, 70.3% were between the ages of 10 and 19 and 20.8% were concussions from football or soccer.[1] There are 3.8 million concussions a year in the United States from sports and physical activity. In 2016, Bryan et al. estimated that each year between 1.1 and 1.9 million sport and recreation-related concussions occur in children 18 and younger.[2] According to Gessel et al., concussions represent 8.9% of high school athletic injuries and 5.8% of collegiate athletic injuries.[3] It is important to study concussions and their mechanisms to be able to prevent them, especially in the athletic population as they are often underreported to avoid a decrease in playing time.

In Volleyball, the most common injured areas are the knee, shoulder, ankle, lower back, and head. Concussion rates in high school volleyball are 4.8% and in collegiate volleyball are 5% and are more frequent in competition rather than practice.[4] The most common mechanism of concussion is a collision with the ball. The potential reason for the ball creating concussions is due to the high velocity in which the ball is traveling during attempted kills used to score points. The average velocity of a women's elite college athlete kill can be between 50 to 70 mph.[5] It is important to consider the velocity of the ball and player positioning during attacks that propose an opportunity to cause a concussion in the defending players.

To determine player concussion risk, the purpose of this study was to analyze the opportunities created during a match that could result in a concussion. Games were coded to

record high-velocity kills, head impacts, occurrences when the blocking player's heads are over the net, and times a player was hit in the head. Studying instances where a concussion could occur could help find the true mechanism of concussions during a competitive volleyball match.

Research Questions and Hypotheses

Research Question 1: How many possible opportunities in a volleyball game are there for someone to get struck in the face or head with the ball from a high-velocity kill? Is this different than six years ago?

Hypothesis 1: There are more opportunities in a game now than six years ago as women are statistically getting taller and can therefore jump higher.

Research Question 2: How many times during a block is someone's head over the net? Is this different than six years ago?

Hypothesis 2: The head of the blockers are above the net more frequently now than six years ago.

Research Question 3: How many times within the games observed in October 2016 and 2022 did a player get hit in the face with a ball? Is this different than six years ago?

Hypothesis 3: Players are hit in the face or head with the ball more frequently than they were six years ago.

Research Question 4: Are the players in the front row being hit in the head with the ball more frequently than those in the back row? Is this different than six years ago?

Hypothesis 4: Players hit in the face with the ball are most likely defending a high-velocity kill. The players in the front row are hit in the head more frequently than the players in the back row. There will be a higher injury rate in 2022 than six years ago.

Assumptions and Limitations

1. The leading concussion mechanism was found to be in contact with equipment according to Kerr et al. They also evaluated contact with surfaces and players, therefore the two equipment pieces must be the ball and the posts to the net. We assume that the ball is the most common mechanism as the posts are padded.
2. Kills and blocks were manually counted while watching Volleymetric videos that were available and may be from varying angles.
3. These data represent only games from Elite Women's Collegiate Volleyball.

Operational Definitions

- Head over the net: At least one inch of the player's head is above the top of the net when jumping to defend.
- High-velocity attack: an attack intended to be a 'kill' which can result in a concussion if it hits a player's head

Clinical importance

Determining how concussions happen in volleyball may allow for prevention strategies to become protocol. Limiting the number of chances there are for the mechanisms to occur will allow athletes to avoid concussions.

Chapter II

Literature Review

Mechanisms of Concussions

Concussions can be defined as transient neurological dysfunction as a result of biomechanical force.[6] The National Athletic Trainers' Association defines concussion as a trauma-induced alteration in mental status that may or may not involve loss of consciousness. Concussions occur from forces applied either directly or indirectly to the skull which results in both acceleration and deceleration of the brain.[7] Symptoms include confusion, disorientation, unsteadiness, dizziness, headache, and visual disturbances. Each concussion is unique due to its mechanism. The symptoms vary depending on the type and location of collision with the head and whether it was protected or not. Linear and rotational acceleration occurs in nearly every instance of concussion. The brain tissue deforms readily in response to shear forces compared to other tissues making this the predominant mechanism of injury. The increase in pressure on the brain results in post-concussive deficits including neuronal dysfunction, impaired connectivity, changes in neurotransmission, and even altered metabolism.[8] From 2001 to 2009 traumatic brain injury-related emergency department visits increased significantly from 153,375 to 248,418, a 62% increase. The highest rates of concussion were among males from 10 to 19 years old, mostly from bicycling, football, soccer, and basketball.[9] In 2016, Bryan et al. found that most children, ages 18 and younger, who sustained a sport or recreational-related concussion were not seen in a healthcare setting for the injury. This number ranges from 511,590 to 1,240,972.[2]

The two leading causes of concussions are football and soccer, followed by motor vehicle accidents, assault, and work-related accidents. Seiger et al. conducted a study to determine if the mechanism of injury plays a role in recovery from concussion in three different groups including

football, soccer, and motor vehicle injuries. Out of the 170,000 Emergency Department visits, 70.3% were between the ages of 10 and 19 and 20.8% were concussions from football or soccer. Recovery was defined as the length of time from the time of injury to the date of clearance for sports or work without restrictions. Documented symptoms were self-reported. The most reported symptom was headaches for all three groups assessed. The second most recorded symptom in the soccer and motor vehicle accident groups was difficulty concentrating while in football this was equal to the symptom of fatigue. The Immediate Post Concussion Assessment Tool or ImPACT is used to help medical professionals diagnose concussions. This tool was used to compare concussion presentation differences due to its mechanism. Results concluded that victims of motor vehicle accidents have lower visual memory and visual motor speed scores compared to athletes with concussions from football or soccer. A lower score correlates with a longer recovery time. Therefore, victims of motor vehicle accidents take three times longer to recover from a concussion than athletes in football and soccer. This study presents limitations and variability in recovery time due to the pressures of athletes to return to play and the potential of symptoms being underreported.[1] This is important to consider because it could correlate to players wanting to return to play at a quicker pace, and therefore, not being fully recovered when doing so. An athlete that returns to play before being fully recovered has a higher chance of reinjury or further injury which can be prevented.

Concussion in Sport

In the United States, each year there are 3.8 million concussions due to sports and physical activity. According to Gessel et al., concussions represent 8.9% of high school athletic injuries and 5.8% of collegiate athletic injuries.[3] A study by Kerr et al. dives deeper into

concussions and their mechanisms in 20 different high school-level sports. The seasons in the 2013-2014 school year were compared to the 2017-2018 school year. They concluded that concussion rates were increasing in sports, however, recurrent concussion rates were decreasing. Girls sustained more concussions and recurrent concussions than boys. Figure 2.1 illustrates recurrent concussion rates in all 20 sports.[10]

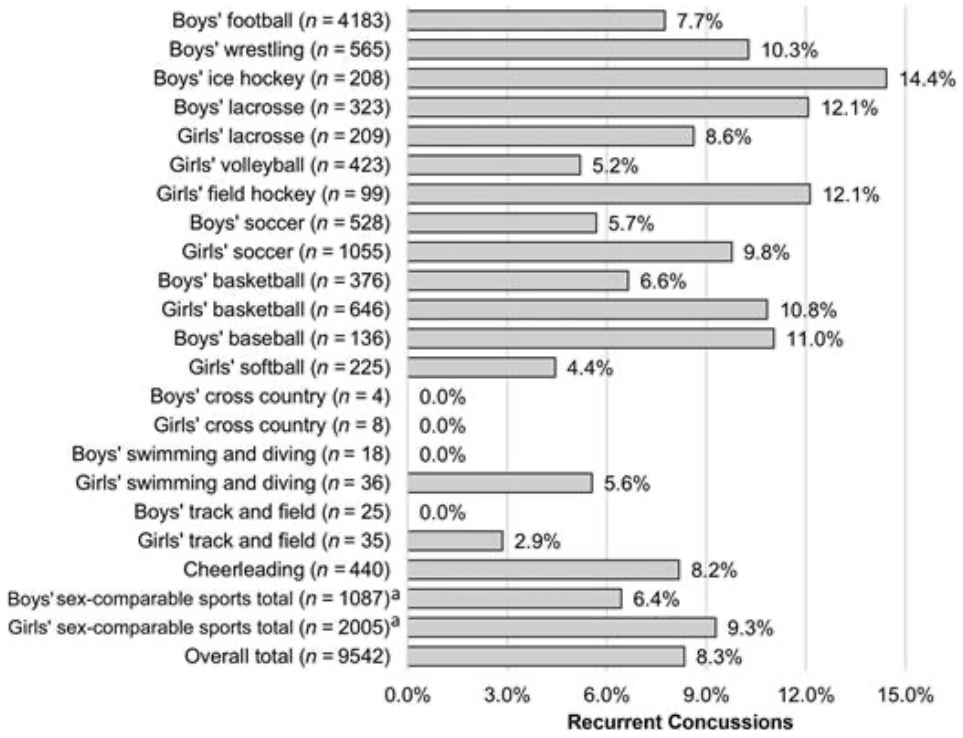

Figure 2.1 Recurrent Concussions[10]

Mechanisms of most concussions reported first came from contact with another person, then a surface, then equipment. Concussions due to contact with equipment occurred more in girls than boys. In 19 out of 20 of the sports, more concussions were reported during competition rather than practice. The opposite occurred in cheerleading. Concussions that did occur in practice usually happened within the first hour of the sports in this study.[10] This data allows for

concussion prevalence to be compared between all 20 sports. Compared to the other sports in this study, girl's volleyball has a lower concussion rate.

Injuries in Volleyball

According to the NCAA injury surveillance system, volleyball has the lowest injury rate of 15 sports with 1 to 10 injuries per every 1000 athlete exposures. Males are more susceptible to injury as they practice more than females on average. In addition to this, players over eighteen years of age are three times more susceptible to injury than those under eighteen.[11]

The body parts that are most often injured in a female volleyball athlete include the knee, shoulder, ankle, lower back, and head, in that order. The knee and shoulder are the most common overuse injuries, non-contact injuries, which occur most often in the practice setting. Contact injuries are a result of the athlete colliding with another player, the floor, or the ball. Sprains and strains are the most common acute injury whereas tendinopathy is the most common overuse injury. Overuse injuries do occur at a lower rate than acute injuries. Specifically, middle blockers have the highest amount of ankle injuries due to this position being required to jump most often. Volleyball and high jump rate sports could be considered high risk for injury among young athletes.[12]

Beach volleyball has fewer ankle sprains than indoor volleyball due to the difference in ground reaction force. Beach volleyball and indoor volleyball differ in injury rates as Juhan et al. conducted a study where there were 170 injuries in beach volleyball and 804 injuries in indoor. The most common beach volleyball injuries were in the shoulder, low back, abdominal muscles, foot, then lastly knee. The most common indoor volleyball injuries were in the knee, shoulder, ankle, low back, and leg.

A study conducted by Chandran et al. dove further into the epidemiology of injuries in the National Collegiate Athletic Association of Women's Volleyball from the 2014-2015 season to the 2018-2019 season. Over this period of time, they found that injury rates switched from being most common in competition to being most common in practice, were more prevalent in the preseason than the regular season and that the most specific injuries reported were lateral ankle ligament complex tears and concussions. This information is illustrated in Figure 2.2.[13]

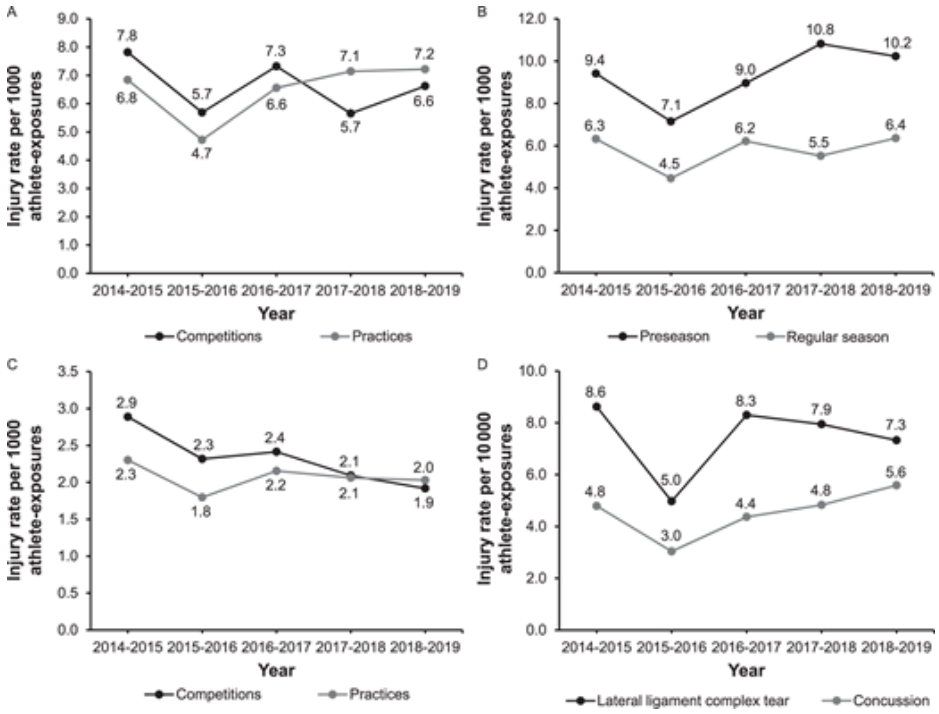

Figure 2.2 Injury Rate per 1000 Athlete Exposures[13]

Chandran et al. also determined which positions are injured the most and by which activity. Non-contact and overuse injuries accounted for over half of the injuries recorded. During the competition, digging and blocking accounted for most injuries while during practice, general play and spiking accounted for more comparatively. The positions that were most frequently injured were outside hitters and middle blockers. Table 2.3 holds the data these results were determined by.[13]

	Overall		Competitions		Practices	
	Injuries Reported (%)	National Est. (%)	Injuries Reported (%)	National Est. (%)	Injuries Reported (%)	National Est. (%)
Activity						
Blocking	323 (13.76)	7041 (12.96)	128 (18.10)	2774 (17.09)	195 (11.89)	4267 (11.21)
Conditioning	48 (2.05)	1515 (2.79)	3 (0.42)	50 (0.31)	45 (2.74)	1465 (3.85)
Digging	326 (13.89)	7141 (13.15)	143 (20.23)	3098 (19.09)	183 (11.16)	4042 (10.61)
General play	806 (34.34)	18 893 (34.79)	200 (28.29)	4845 (29.86)	606 (36.95)	14 048 (36.89)
Passing	112 (4.77)	2537 (4.67)	43 (6.08)	1009 (6.22)	69 (4.21)	1528 (4.01)
Serving	52 (2.22)	1090 (2.01)	10 (1.41)	196 (1.21)	42 (2.56)	894 (2.35)
Setting	57 (2.43)	1358 (2.50)	21 (2.97)	507 (3.12)	36 (2.20)	851 (2.23)
Spiking	262 (11.16)	6291 (11.58)	64 (9.05)	1505 (9.27)	198 (12.07)	4787 (12.57)
Other/unknown	361 (15.38)	8441 (15.54)	95 (13.44)	2245 (13.83)	266 (16.22)	6196 (16.27)
Position						
Libero	372 (15.85)	8174 (15.05)	128 (18.10)	2773 (17.09)	244 (14.88)	5401 (14.18)
Middle blocker	512 (21.82)	11 420 (21.03)	139 (19.66)	3130 (19.29)	373 (22.74)	8290 (21.77)
Outside hitter	645 (27.48)	15 089 (27.78)	204 (28.85)	4743 (29.23)	441 (26.89)	10 346 (27.17)
Setter	333 (14.19)	8213 (15.12)	116 (16.41)	2799 (17.25)	217 (13.23)	5414 (14.22)
Opposite/right-side hitter	243 (10.35)	5509 (10.14)	64 (9.05)	1480 (9.12)	179 (10.91)	4029 (10.58)
Other/unknown	242 (10.31)	5902 (10.87)	56 (7.92)	1303 (8.03)	186 (11.34)	4599 (12.08)

[a] Data presented in the order of reported number, followed by the proportion of all injuries attributable to a given category. Data pooled across event types are presented overall, and separately for practices and competitions. National estimates were produced using sampling weights estimated on the basis of sport, division, and year. A reportable injury was one that occurred due to participation in an organized intercollegiate practice or competition, and required medical attention by a team Certified Athletic Trainer or physician (regardless of time loss). Only scheduled team practices and competitions were retained in this analysis.

Table 2.3 Distribution of Injuries by Activity and Position[13]

Concussions in Volleyball

There is not much of a difference between concussion rates in high school volleyball and collegiate volleyball players as high school has a 4.8% and collegiate has 5%.[4] It is common to see that an athlete that has had a concussion is more likely to withstand a lower extremity injury as their neuromuscular changes put them at high risk for musculoskeletal injuries.[14] There is more research conducted about injury rates in volleyball rather than specifically concussions in volleyball.

Concussion rates are higher during competition rather than in practice, unlike other injuries. This often resulted from the player coming into contact with another player, the ball, or the floor. Meeuwisse et al. found that the most common mechanism of concussion in volleyball resulted from the player being hit in the head with the ball. After this, the most common was two players coming in contact and then the player coming in contact with the floor.[5] Kerr et al. have

similar findings as in their study over half of the mechanism of concussions in women's volleyball was coming in contact with equipment. Next was contact was a surface, then contact with another person.[10] This is represented in Table 2.4. They also found that contact with another person resulting in concussion was higher in boys than girls in all of the sports researched.

Sports	Injury Mechanism, n(%)				Total, n(%)
	Contact with Another Person	Contact with Surface	Contact with Equipment	Other	
Volleyball	79 (18.7)	105 (24.8)	228 (53.9)	11 (2.6)	423 (100.0)

Table 2.4 Sport-Related Concussion Counts Injury Mechanism in Volleyball[10]

Kerr et al. collected data on the timing of concussions within the competition. Pre-competition warm-ups were a relatively small percentage of recorded concussions except in girl's volleyball and girl's softball. The National Federation of High School Associations released a rule to be in effect from 2018-2019. It stated that balls were not allowed to be hit over the net in warm-ups in hopes to lower concussion rates.[15] This is because oftentimes an opposing team could spike a ball over the net and unintentionally hit an athlete that may not have been paying attention. Pre-competition warm-up was the second time of the event with the highest concussion rates. The first highest was during the second set.[10] This data is represented in Table 2.5.

Sport	Time in Event	n (%)
Girls' Volleyball	Pre Competition or Warm Ups	65 (27.5)
	First Set	5 (2.1)
	Second Set	68 (28.8)
	Third Set	38 (16.1)
	Fourth Set	8 (3.4)
	Fifth Set	3 (1.3)
	Missing	49 (20.8)

Table 2.5 Distribution of Timing of Concussions in Volleyball

The Velocity of the Ball in Volleyball

Ferris et al. conducted a study to find a correlation between spiking speed and physiological variables of the female volleyball player. He begins by describing certain characteristics that have proven to be advantageous to the female volleyball player including having a greater height, greater vertical jumping distance, greater mass, greater upper body strength, and lower body fat percentage. These have proven to help overall playing ability but not necessarily specific skills. This study focuses on the skill of spiking as it is the most important offensive weapon in competition. The success of the spike is determined by trajectory and velocity. The two characteristics with significant correlation to spiking speed include arm extension torque at 270º per second and standing reach. This arm extension has the highest torque of the forearm motions tested at all speeds. Players with the greatest arm extension torque generate the fastest spikes and velocities of the ball. The standing reach allows the player to avoid lengthy vertical jumps and to hit the ball downward quickly. However, those with greater standing reach tend to have slow spiking speeds. Overall, Ferris et al. concluded that shoulder extension strength at high speed is the dominant alterable physiological variable related to spiking speed.[16] Therefore, players with these physical attributes have an advantage in competition over the players who do not.

Changing Concussion Protocols

Learning the mechanisms of concussions in volleyball can help to create prevention techniques so players can avoid them. Concussion rates can also decrease with changes to return-to-play protocols. McInnes et al. reviewed traumatic brain injury literature and found that the presentation of long-term symptoms and cognitive impairment is underestimated by only

15% of the population of first-time concussed individuals. Their findings do not support this conclusion and argue that a higher percentage of the population with first-time concussions will suffer long-term cognitive impairment, including difficulty in executive function, learning, memory, attention, processing speed, and language function.[17] Concussion protocols need to be examined to address the long-term consequences of the injury. Today, concussions are no longer graded in severity, therefore, athletes who sustain a concussion are required to go through the entire return-to-play protocol process regardless of concussion severity. This is important as it requires athletes to take time to recover.

In addition to this, high school athletes with a grade one concussion differ from collegiate athletes with a grade one concussion as they have prolonged memory dysfunction. Return-to-play protocols should account for this difference and require a longer recovery for high school athletes. Volleyball Canada has already adopted new protocols to prevent concussions including the 'Warm Up Protocol' in 2018. This states that a player is not permitted to run under the net to the opposite side of the court to retrieve their ball during a standard hitting warm-up routine.[19] It is necessary to adapt concussion prevention and return-to-play protocols according to current findings.

Summary

Injuries in volleyball occur at a rate of 7.2 per every 1000 athlete exposures.[15] Of these injuries, about 5% are concussions. It seems as though a leading cause of those concussions is due to contact between the ball and the player's head. Given the high velocity of a kill in volleyball, it would make sense that hits to the head or face might cause a concussion.

Chapter III

Methodology

VolleyMetrics

VolleyMetrics is a software that functionally offers data analysis. Matches date back to 2016 in both the professional and collegiate leagues and can be easily searched. The software offers data to the right of the screen as the match plays. This data includes the player, the event, and the score and game. The user can go directly to certain events of the game by clicking on them from the data list rather than fast-forwarding through the game. Another feature of the software is the ability to present certain events to find them more quickly. Detailed statistics of the game are offered by each player and event as well.

Participants

Data were collected from 48 volleyball games covering two weekends in October 2016 and two weekends in October 2022 from volleyball teams. The specific dates include October 14th, 15th, 16th, 21st, 22nd, and 23rd in 2016 and October 14th, 16th, 21st, and 23rd in 2022. These dates offered the most matches to observe in relatively the same time frame. Mid-season ACC volleyball matches were viewed.

Collecting Data

VolleyMetrics allows for quick and easy access to finding attacks that were specifically fast velocity kills. Clicking the event allows for repeated observations of this event allowing for data to be collected. Data collected for each high-velocity attack included which team attempted the kill, the score of the game, how many people jumped to block the kill, how many of the

heads of the blockers were over the net, if anyone's head was hit, and what row the person hit was in.

First, the specific match was selected to watch. Once selected, the option of filtering for 'attacks' is available to the right. This allows the user to click on every attack no matter if it is a kill or not. Instead of watching the entire game, the user can click through each attack. If the attack is considered a high-velocity kill then data is collected, if not then it is skipped. When collecting the data on the high-velocity kill the user clicked the specific attack a couple of times to rewind to where it starts and collect everything that is required.

The talliers had to use their best judgment when deciding if an attack was a high-velocity attack that should be recorded. When recording the data, the score of the game at the specific attack will be documented for reference. This is listed on the right when clicking on the specific attack. Next, the total number of defenders that jump to block the ball must be counted. Of these defenders in the front row, the number of heads above the net must be recorded. Lastly, the data collector must take note of if the ball hit a player in the head as well as which position this player was in. To collect all of this information, the attack must be watched at least three to four times and may need to be zoomed in on for accurate recording.

In total, 48 games were tallied. There were six talliers who were each assigned to 16 games. Each game was tallied twice by two separate talliers to ensure that there was accurate data collected. To create consistency in the data collected, all the talliers were paired with each other an equal number of times. Due to the number of games, three pairs were repeated one more time compared to the others.

Data analysis

The number of times a high-velocity attack occurred as well as the number of times a defender's head was over the net during a high-velocity attack was represented as a percentage of times it occurred over a game. To obtain a percentage, the number of high-velocity attacks was divided by the total number of attacks. The same was done for heads over the net. The number of heads over the net was divided by the total number of blockers for the game. To determine the difference in the percentage of high-velocity attacks and heads over the net, the data from 2016 were compared with the data from 2022 with a Kruskal-Wallis H Test using SPSS Version 29.

The incidence of the total number of times the ball hit a player's head was then calculated using the average number of high-velocity kills as the denominator and the number of times the head was hit as the numerator giving an occurrence per 1000 exposures. The same was performed for head hits to players in the front and back row.

Chapter IV

Results

High-Velocity Attacks

The mean percentage of high-velocity attacks in 2016 was 57.53% and in 2022 was 60.40%. The Kruskal-Wallis H test did not indicate a significant difference between high-velocity attacks in 2016 and 2022 (H value 1.574, p = 0.210). The mean percentage of high-velocity attacks for all games was 59.21%. The smallest amount of high-velocity attacks seen in a game was 45.53% and the largest amount was 72.78%. There was a standard deviation of 7.39% between the 48 games used. (Table 4.1).

Heads Over the Net

The mean percentage of heads over the net in 2016 was 46.14% and in 2022 was 39.22%. The Kruskal-Wallis H test did not indicate a significant difference between heads over the net in 2016 and 2022 (H value 2.762, p=0.097). The mean percentage of heads over the net for all games was 41.62%. The smallest amount of heads over the net seen in a game was 10.03% and the largest amount was 76.34%. There was a standard deviation of 13.79% between the 46 games used. (Table 4.1)

	Percentage of High Velocity Attacks			**Percentage of Heads Over the Net**		
	2016	2022	Total	2016	2022	Total
N	20	28	48	20	26	46
Mean	0.5753	0.604	0.5921	0.4614	0.3922	0.4162
Std. Deviation	0.0766	0.0709	0.0739	0.1484	0.1123	0.1379
Minimum	0.4556	0.4553	0.4553	0.1698	0.1003	0.1003
Maximum	0.6995	0.7278	0.7278	0.7634	0.5596	0.7634
Kruskal-Wallis H			1.574			2.762
Asymp. Sig			0.21			0.097

Table 4.1 Descriptive and Test Statistics

Prevalence of High-Velocity Attacks Hitting a Player's Head

There was a prevalence of 8.46 heads hit per every 1000 exposures to high-velocity attacks in 2016. There was a prevalence of 11.34 heads hit per every 1000 exposures to high-velocity attacks in 2022 (Table 4.2).

Year	Number of Times Heads Were Hit	Total Number of High Velocity Attacks	Heads Hit per 1000 Exposures
2016	25	2955	8.460236887
2022	47	4145.5	11.33759498

Table 4.2 Heads Hit Per 1000 Exposures

Heads Hit in the Front Row vs Back Row

In 2016, there was a much higher number of players in the front row being hit in the head than in the back row with 20 players in the front row and 5 players in the back row. In 2022, the players in the front row are still hit in the head more times than the back with 28 players in the front row and 19 players in the back row. In both 2016 and 2022, about 6.8 heads are hit per every 1000 exposures to a high-velocity attack in the front row. However, in the back row, there are only 1.7 heads hit per every 1000 exposures in 2016 and in 2022 there are 4.6 heads hit per every 1000 exposures. (Table 4.3)

Year	Total Number of High Velocity Attacks	Heads Hit in Front Row	Heads Hit in Front Row Per Every 1000 Exposures	Heads Hit in Back Row	Heads Hit in Back Row Per Every 1000 Exposures
2016	2955	20	6.768189509	5	1.692047377
2022	4145.5	28	6.754311904	19	4.583283078

Table 4.3 Location of Heads Hit Per 1000 Exposures

Chapter V

Discussion

Comparing Results with Previous Literature

As discussed in Chapter I, Meeuwisse et al. found that the most common mechanism of concussion in volleyball resulted from the player being hit in the head with the ball. Kerr et al. found that with over half of the volleyball concussions in their study, the mechanism of injury was contact with equipment (Table 2.4). After analyzing the data from Volleymetrics, it was found that out of the 48 games analyzed, in 32 games there was at least one instance of a player being hit in the head during a high-velocity attack. Some games had as many as six instances where a player was hit in the head with the ball during a high-velocity attack. Therefore, there seems to be a high frequency at which a player can be hit in the head. While we were not able to determine if these hits resulted in a concussion, it can be noted that they may lead to a concussion.

There were 8.46 heads hit per every 1000 exposures to high-velocity attacks in 2016 and 11.34 heads hit per every 1000 exposures to high-velocity attacks in 2022 (Table 4.2). This is a large number as Chandran et al. found that in the 2016-2017 season, volleyball players had an injury rate of 6.6 per every 1000 athlete exposures. In the 2018-2019 season, this increased to an injury rate of 7.2 per every 1000 athlete exposures.[15] We saw an increase in hits to the head which is consistent with the increase in injury rate in volleyball overall. Interestingly, there were more frequent occurrences of heads being hit during a volleyball game in 2016 than there were injuries in the 2016-2017 season. This demonstrates that while we do not know if these hits created injury, the number of hits to the head is significant. Additionally, there was a trend for an increase in being hit in the head over six years. Which is consistent with the trend seen in overall

injury data. Finally, the increase in the number of back-row players being hit in comparison to front-row players may be significant to increasing injury risk. This can be assessed by determining in which rows the injury rates occur.

Clinical Significance

The average percentage of high-velocity attacks within a game was 59.21%. This means that over half of the total attacks in a game were high-velocity, and therefore, an opportunity for a concussion to occur if it hits a player in the head. On average, we viewed games that had about 250 attacks. Using the average percentage of high-velocity attacks in a game, there are about 148 high-velocity attacks in a game with 250 total attacks. With the back-row incidence rate of 4.5 heads hit per every 1000 exposures, there is a high likelihood of a back-row player being hit in the face with a high-velocity kill every 2 games. In other words,

We don't know if the players that were hit in the head with a high-velocity attack ended up with a concussion, however, there was certainly an opportunity for one to occur. The players that are most frequently being hit in the head during a high-velocity attack are those in the front row. We often saw that players were able to avoid being hit in the head by getting their hands up as they were going up to block the ball. These instances were very close calls and required multiple viewings to ensure the player was not actually hit in the head due to the quickness of the event. The players in the front row are usually ready with their hands right above and in front of their faces, to prepare for blocking the ball. Having their hands in this position allows them to brace a hit and avoid having the ball hit them in the head and a potential concussion. Additionally, in those times when front-row players did get hit, their necks were braced and ready, which may protect them from concussion.

However, the players in the back row were often preparing to dig for a ball, so their hands were much lower than their heads. Therefore, these players were not in a great position to protect their heads from being hit if needed. Having players in both the front and back row have their hands in a position that allows quick reaction to blocking the ball and blocking their head may be an advantageous change in training to avoid concussions.

Limitations

Although Volleymetrics provided readily available videos for us to analyze, many limitations came along with this data collection method. The first major limitation was the video quality itself. Some videos were taken from steep angles making it hard to tell if the player's heads were going over the net on the opposite side of the court. Other videos were of poor quality making it hard to be sure if a player was hit directly in the head with the ball.

In addition to the video preventing absolute assurance of the heads being over the net, the hair of the players would get in the way. When a player jumped at the speed and intensity they did to block the ball from going over the net, their hair would quickly rise above their head. This resulted in multiple rewatches of the player's jump to be sure that their head was over the net and not solely their hair. Hair also created a problem as it would blend into the dark backgrounds of some of the volleyball courts.

Lastly, having different people tally different games did lead to discrepancies in the data. To mitigate these differences all six talliers tallied the same game to find if some people were counting too many or not enough heads going over the net than there were as well as high-velocity attacks. Comparing the data between all six talliers allowed us to pinpoint where the differences were coming from. After this, instances that would and would not be counted

were highlighted for individuals struggling. Although we did our best to mitigate the discrepancies, there was no way to produce identical data collection between six different people due to human error. Because of this, two people would tally each game. Everyone was paired an equal amount of times and had an equal amount of games to tally. When going through the data, if the collections were close enough, an average was taken. If the data had vast differences, the person's data that had the least mistakes was taken.

Future Research

If this study were to be redone, a larger time frame may produce statistically significant differences. Eight years may have been too short of a period for players to have increased in size as this is a trend seen over decades, therefore, looking at a larger one may lead to there being a larger difference in the percentage of high-velocity attacks within a game or percentage of heads over the net. Over a larger period, the physical differences may be more prevalent similar to the differences in certain teams.

Another important task would be to combat the discrepancies in tallying. Although everything was clearly defined and many examples were gone over, it may have been helpful for all six talliers to tally more games together. This could be done by all the talliers watching a game simultaneously and debating if each hit is a high-velocity one and why they think this. Debating hits together may offer insight as to why one person might count a hit over another and can help all six of the talliers be on the same page about when to count a certain instance or not. Having everyone learn to be on the same page by practicing tallying together will allow for more accurate results to be recorded.

It would be fascinating to follow up with the players that were hit in the head from a high-velocity hit. As expected, many hits caused the player to be taken aback and need a few seconds to recover. Shockingly there were numerous occurrences where players seemed completely unphased by the hit. Following up about the experience and if it led to a concussion could help to determine the main mechanisms of concussions in volleyball. Another follow-up that could be done using this data would be where the hands of the back-row players were before they were hit in the head with a high-velocity attack. If they are consistently preparing to dig the ball then they will not be able to get their hands up to block their head in time if that scenario occurs. If this is the case, it may truly be beneficial to have them be prepped with their hands directly in front of them. That way they can quickly get their hands down to block the ball or up to block their face if needed.

Interestingly, teams that are known for having records better than others had players that were easily able to get their heads above the net, whereas, the teams with worse records were not able to do such. This could mean that the better teams can recruit players who have physical advantages such as being taller and stronger. Learning more about this difference would help find patterns in the mechanisms of concussions in volleyball leading to implementing strategies or rules to prevent them. There may be a pattern of the worse teams sustaining more concussions than the better teams due to their players not having the same physical advantages. However, further research would have to be done in this scenario as well as discussions on if there is a pattern, should this result in new regulations that try to prevent concussions. For now, the best way to combat the increase in concussions in the back row players would be to prepare to block the ball with heads higher up rather than low, preparing to dig so they can block their head if needed.

Conclusion

There are 3.8 million concussions a year in the United States from sports and physical activity. The concussion rate in collegiate volleyball players is 5% with the majority of these occurring as a result of contact with the equipment (the ball).[4,] It has been determined that the average speed of a volleyball kill in elite-level college volleyball is 50-70 mph.[5] This study analyzed the opportunities created during a volleyball match that could result in head impacts with the ball and lead to a concussion.

Using VolleyMetrics, a software that offers videos of volleyball matches, 48 Mid-season ACC volleyball games (20 in 2016 and 28 in 2022) were coded to record high-velocity kills, head impacts in front-row and back-row players, and occurrences when the front-row player's heads were over the net during blocking. Data were collected to answer if there were differences between 2016 and 2022 in the percentage of high-velocity attacks, the percentage of heads over the net, and the number of heads hit as well as in which rows.

A Kruskal Wallis H Test through SPSS Version 29 concluded that there was not a significant difference in the percentage of high-velocity attacks and the percentage of heads over the net in 2016 and 2022. The average percentage of high-velocity attacks was 59.21%. There was an average of 250 attacks a game from the 48 games analyzed, therefore, 148 of the 250 attacks would be deemed high-velocity. This is 148 times there is an opportunity for a concussion to occur.

Although the difference between time periods was not significant, the incidence rates for hits to the head might explain the number of concussions that are seen in volleyball. For front-row players, the overall incidence rate of ball hits to the head was 6.8 per every 1000 exposures. There was an increase in the incidence rate of back row players hit in the head from

1.7 per every 1000 exposures in 2016 to 4.6 per every 1000 exposures in 2022. While we are unable to determine if these impacts to the head with the ball result in concussion, the incidence of head hits is concerning as they may lead to injury.

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