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Concussion Prevention and Technology

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A Synthesis Project
Presented to the
Department of Kinesiology, Sports Studies, and Physical Education
SUNY Brockport

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Education
(Athletic Administration)

by
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Department of Kinesiology, Sport Studies, and Physical Education

Title of Synthesis Project:

Concussion Prevention and Technology

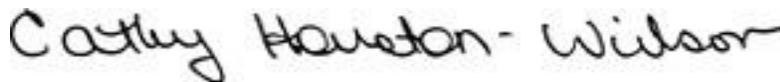


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Instructor Approval

Date

Accepted by the Department of Kinesiology, Sport Studies, and Physical Education, The College at Brockport, State University of New York, in partial fulfillment of the requirements for the degree Master of Science in Education (Physical Education).



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Abstract

As more information emerges involving the long-term effects of concussions on athletes, so does the push to protect them, and in turn, continue to encourage participation. Concussions are extremely prevalent in the sport of football in particular, despite athletes wearing protective equipment such as helmets. Analysis of previous research shows that technological advancements in video analysis as well as impact tracking systems can positively influence player safety. When combining this with continued advancement in equipment development, testing, and proper usage, especially in the sport of football, athletes will be better protected. The purpose of this synthesis is to review the literature on the effects of technology on reducing the risk of concussions in sports. A second purpose of this synthesis is to review the importance of football equipment and its effects on concussion prevention.

Chapter One: Introduction

When athletes take part in contact sports such as football, they are likely aware of the risks that are involved. Sprains, broken bones, and torn ligaments are just a few of the common injuries that can occur in sports, but can be more prevalent in contact sports. With increasing technology, more serious injuries are no longer career-ending. With proper medical attention and rehabilitation, athletes can sustain serious injuries, and in time, return to play with little or no lasting effects. New technology has also shed light on an injury that is not detected by the naked eye, concussions. “Concussion is a common injury in sport and occurs in athletes of all ages, with varying incidence rates across contact and limited-contact sports” (Gardner, Quarrie, & Iverson, 2019).

“Through the years there has been an alarming increase in the number of football players in the NFL that have been reporting having short term and permanent sport-related mild and traumatic head and spinal injuries during and years after they were done playing football in the NFL” (Herbert, 2015). The 2015 movie starring Will Smith, titled “Concussion” (Landesman, 2015), along with numerous former athletes opening up about their daily struggles after retirement, has triggered a rush to decipher what concussions are, how they happen, and what their lasting effects could be. There is also an effort to uncover more information on how to better protect athletes against concussions.

Injuries are not uncommon in sport and this is no different with the sport of football. In fact, rules have been altered and equipment has been manufactured to try and make the game safer since the beginning. Bartsch et al. (2012) highlighted some history involving the dangers of football in their investigation into helmet protection. The first organized game of football took place between Princeton and Rutgers in 1869. By 1893, the formation called the “flying wedge”

was outlawed to help reduce injuries. Three years later, the first leather headgear was introduced, and by 1905, after numerous fatalities and hundreds of injuries, President Roosevelt endorsed safer rules of play. Facemasks were invented in 1935 and hard-shell helmets started being used after WWII. Since then, organizations such as the National Operating Committee on Standards for Athletic-Equipment (NOCSAE) and the Mild Traumatic Brain Injury Committee established by the NFL have come about in an effort to better regulate the game and make it safer. Currently, all football helmets must meet NOCSAE testing standards in order to be used.

Even with the protection of helmets, players are still at risk for head trauma. Obvious head trauma is seen when players remain unconscious after hits, but not all head trauma leads to that. Concussion detection has come a long way. In 2013, football helmet manufacturer Riddell Inc. introduced the InSite Impact Response System. “The Riddell Insite Impact Response System uses new integrated technology to monitor and record significant head impacts sustained during a football game or practice” (Abreu, Edwards, & Spadley, 2016).

To go along with concussion detection, steps have also been made to help athletes’ post-concussion. “Recommendations about returning to play have undergone subtle but important changes over the course of the four consensus statements” (McNamee, Partridge, & Anderson, 2015). The NFL has taken steps as well to continuously update their return to play guidelines and came up with their own concussion protocol that players enter once they are diagnosed with a concussion. “The Concussion Protocol is reviewed each year to ensure players are receiving care that reflects the most up-to-date medical consensus on the identification, diagnosis, and treatment of concussions” (Concussion Protocol and Return-to-Participation Protocol, 2018). These few examples are positive steps, but one thing remains certain... concussions are not going away and with increasing participation across the country, concussion numbers increase as well.

Statement of Problem

“Despite the large number of scientific studies conducted to explore the pathological psychology of concussion, there is still a lack of agreement among medical researchers and sports medicine clinicians about the precise nature of mild traumatic brain injury” (McNamee, Partridge, & Anderson, 2015). This same sentiment was echoed when authors explained how concussions in athletes has been historically hard to evaluate due to the “lack of standardization of injury definitions and methods used to collect and report data” (Gardener, et al, 2019). They also go on to explain that there are multiple definitions of concussions used in epidemiological studies, all of which involve trauma to the head, resulting in numerous symptoms. With that being said, it is widely agreed upon that concussions occur from hits to the head, but not every hit to the head.

With continued understanding of just what concussions are, comes continued adjustments for how to protect against them. Although there has been organizations constructed to help with injury prevention, rule changes in sport, and continued efforts to protect athletes, concussion numbers continue to increase. “It is estimated that 1.6 million to 3.8 million concussions occur annually as a direct result of athletics” (Daneshvar, et al, 2011). “In 1 study, rates of concussion doubled per 1000 high school athlete-exposers between 2005 and 2012” (Greenhill, et al, 2016). Professional sports, despite having much more money and better equipment, facilities, and doctors, are also still at a great risk of concussion. “Sport-related concussion is common, with an incidence of up to 18 concussions per 1000 athlete hours in professional sports” (Davis et al, 2018). According to Bartsch et al (2012) “American football is the leading cause of sports-related concussion in the US”. Lessley et al (2018) explained that in the NFL, despite 47 rule changes since 2002, concussions continue to remain a concern and there is an estimated more

than 0.6 concussions per game. Based on these statistics, it is clear that more still needs to be done to protect athletes.

Purpose of the Synthesis

The purpose of this synthesis is to review the literature on the effects of technology on reducing the risk of concussions in sports. A second purpose of this synthesis is to review the importance of football equipment and its effects on concussion prevention.

Operational Definitions

Concussion- “A traumatic brain injury induced by biomechanical forces” (Gardner, Quarrie, & Iverson, 2019)

Research Questions

1. What technology is being used currently to help prevent concussions in youth, high school, and professional athletes?
2. What role does football equipment play in preventing concussions in athletes?
3. What can still be done to help prevent concussions in athletes?

Delimitations

1. All articles used in the synthesis were peer reviewed and full text.
2. All articles used in the review were published between 2011 and 2021.
3. Articles focused on the impact of technology on concussion prevention in athletes or proper fitting of equipment and the effect on concussions

Chapter 2: Methods

The purpose of this synthesis is to review the literature on the effects of technology on reducing the risk of concussions in sports. This chapter highlights the databases, process and language used to uncover the information for this synthesis. Peer-reviewed literature was found on databases through SUNY Brockport's Drake Memorial Library website. The articles were found primarily through EBSCO Host, Academic OneFile, and Google scholar, all of which were located through the Articles, Databases, and Journals sections on the library home page, as well as databases by subject, which led to Kinesiology, Sports, & Phys. Ed.

The search was first narrowed by choosing the specific subject, Kinesiology, Sport Studies, and Phys. Ed. Within EBSCO Host, SPORTDiscus was the primary database used for research. The criteria used for finding information included peer-reviewed articles, and searches were limited to articles published between 2011 and 2021. Articles were data-based, full text articles.

The National Football League website was also used in this synthesis to detail specific concussion protocols. These protocols were found by searching the NFL.com website on Google, selecting the "Players" tab, followed by selecting "Health and Safety". Next, the "Health and Wellness" tab was selected, which lead to the "Players Care" tab. This takes the researcher right to "featured articles". The first highlighted article was "Concussion Protocol and Return-To-Participation Protocol", published in 2018.

A number of key words and terms that were relevant to the research question were used to narrow down the search. They include *concussion*, *sport*, *definition*, *technology*, *football*, and *helmet*. By simply searching *concussion*, 2,615 results were uncovered. By combining some of these terms such as *concussion definition*, *concussion technology*, *football helmet technology*,

and *Concussions in football*, results were narrowed even more to help focus on the research question. The process of mixing terms and key words was repeated numerous times.

To first understand the true definition of *Concussion*, the key word along with *definition* and *sport* was applied to SPORTDiscus. After narrowing the research down to academic journals published between 2011 and 2021, the search resulted in 58 articles. 2 of these articles were used in this synthesis paper. Next, key words *helmet* and *technology* replaced the key words *definition* and *sport*. This produced 15 results after limiting the articles to journals published between 2011 and 2021. By inserting the key words *football helmet technology*, 16 results were found, only one of which was new.

By going through the Academic OneFile and using the key words *Concussion* and *Technology*, 31 academic journals were found. By narrowing the publication years to 2011 to 2021, the search was narrowed to 24 articles. One article was found to be useful from this search. Adding key words *helmet technology* and *concussions*, while also keeping the same publication date between 2011 and 2021, 3 more articles were found, one of which being useful to the research.

Articles were taken from numerous journals revolving around sports, health, and medicine. These included *Journal of Biomechanics*, *The Journal of American College of Sports Medicine*, *Hawai'i Journal of Medicine & Public Health*, *The American Journal of Sports Medicine*, *British Journal of Sports Medicine*, *Journal of Neurosurgery*, and lastly *Sage Publications: Sports Health*.

The main challenge for this research topic was the reality that concussions in sports, and football in general is a fairly new topic. Researchers are just now discovering the long-term effects from traumatic brain injuries. Unlike a broken bone or torn ligament, you cannot see the

effects of a concussion right in front of you. Leagues such as the NFL were also slow to acknowledge the dangers and long-term effects of concussions and therefore, it has taken some time for preventative measures to be put into place. Research is becoming plentiful on the causes of repeated concussions, but technology to help prevent them is still behind and not a ton of studies have been done yet compared to other topics in sport.

Chapter 3- Review of Literature

The purpose of this chapter is to review the literature on the effects of technology on reducing the risk of concussions in sports. The topics that will be explored in this chapter include: technology that is being used to help prevent and track concussions, the importance of proper football equipment and how it can help better protect the athlete from concussions, as well as future technology and what can still be done to help protect athletes against concussions. A review of the literature found that these topics address current problems leading to concussions in football, and could also point how to better protect athletes through technology.

When you think of the evolution of football, many people have seen increases in padding, more protection, and better helmets through the years. In turn, it would make sense that players would be better protected from concussions because, at one point, players wore only leather helmets. Today, helmets are made from hard plastic, with padding and metal facemasks. In reality, there can still be a lot done to increase player safety when it comes to concussions.

Current Technology to Help Protect Athletes from Concussions

Foam was studied in helping stop concussions by Nakatsuka & Yamamoto (2014). In their study, Nakatsuka and Yamamoto recognized the hard-outer layer of football helmets, and looked to investigate whether or not a foam outer layer would be beneficial in reducing impact potential. These authors conducted the study by placing a Riddell helmet on a boxing mannequin. The Riddell helmet had a built-in Head Impact Telemetry System (HITS) that recorded the location, magnitude, duration, and the direction of up to 250 impacts. 1.3 cm of polyolefin foam was applied to the helmet, and the helmet was struck with a pendulum holding a second helmet at the end of it. This process was repeated nine times, and the authors concluded

that adding a foam layer to the exterior of the helmet does in fact reduce the impact severity and injury potential for concussions.

The use of video analysis is becoming extremely prevalent in many different leagues to help with concussion spotting and prevention. Davis et al. (2018) reviewed numerous guidelines from professional sports leagues, both nationally and internationally. The authors invited medical advisors and officers from leagues including the Australian Football League, National Football League, Cricket Australia, Major League Baseball, the National Hockey League, National Rugby League, and finally World Rugby. Each sport was asked to complete a standardized questionnaire involving the use of video review for concussion assessment. Out of the 7 sports to participate in the questionnaire, only Major League Baseball has yet to incorporate video review into its concussion protocol. The National Football League in particular, has certified trainers watch live video feeds to identify head injuries or potentially suspicious hits to the head. This information is relayed down to the sideline so a player can be pulled if necessary.

The study done by Lessley et al. (2018) also used video analysis to analyze concussion, but in a slightly different way. The authors in this study looked at video of reported concussions during the 2015-2016 and 2016-2017 seasons of the National Football League. In their study, each concussion was viewed, and categorized based on the details involving the incidents. The authors found that cornerbacks sustained the most concussions, followed then by receivers, linebackers, and then offensive linemen. 28% of all concussions came from running plays while another 21% came from punt or kickoff, which are considered special teams plays. These plays are not considered to be offense or defense. The authors also found that compared to previous seasons where helmet-to-helmet hits caused majority of concussions, helmet-to-body and helmet-to-ground impacts were more prevalent. The authors noted that not only could

concussion video analysis help identify common concussion-causing plays or more at-risk players, it can be a good tool for concussion countermeasures. Video analysis can help teams like the National Football League stay on top, and ahead of, concussions.

In the study done by Campbell et al. (2020) video analysis was used to help test the validity of the Head Impact Telemetry (HIT) System. The HIT System is the most commonly used head impact sensor in football (Campbell, et al., 2020). The authors explain that the HIT System has been useful in tracking impacts in athletes during play, and has even been instrumental in assisting in rule changes and modifications. One significant one in particular, was moving kickoffs up 5 yards from the 30 to the 35-yard line. Doing so “increased touchbacks in professional football by 35%, reducing the likelihood of players sustaining potential concussions”. This change was assisted by data from helmets fitted with sensors that showed the most severe collisions occurred from plays similar to kickoffs and kick returns.

The study done by the authors confirmed that the HIT System’s impact detection and location accuracy is up to 70% accurate on the special teams plays observed, which was supported by video analysis of game film.

Proper Football Equipment and Fitting

Helmet design and better technology in equipment can play a critical role in preventing concussions. Rowson et al. (2014) studied data collected over a 5-year span involving 1,833 college football players. In the study, each player was equipped with helmet-mounted devices that collected head impact exposure data such as impact severity, frequency, and impact location. Each player wore one of two helmets: a Riddell VSR4 or a Riddell Revolution. 1,281,444 head impacts were recorded in the study, and 64 concussions were diagnosed over the time period. In the study, 322,725 head impacts occurred to players wearing VSR4 helmets, along with 27

concussions, meaning 8.36 were sustained for every 100,000 head impacts. Players wearing the Revolution helmet sustained significantly more head impacts, at 958,719, and 37 concussions were reported, but had a much lower amount of concussions sustained per 100,000 impacts, at 3.86. This data shows evidence that helmet type and design can play a factor in player safety when it comes to concussions.

Collins et al. (2016) performed a similar study where they reviewed concussion and helmet data from 2008 to 2013, submitted by certified athletic trainers of the participating schools. Their goal was to explore whether or not concussion characteristics varied based on helmet age, reconditioning status, manufacturer, and model. Overall, they reviewed 2,900 reported concussions and, for the most part, the authors concluded that new and reconditioned football helmets, the most common helmet manufacturers and models available at that time, provided very similar protection to high school athletes based on concussion symptoms, symptom resolution, and return to play time. The need for continued studies such as this one is important because, as the authors pointed out, as new technology and helmet models emerge, there will also be a need to spot potential differences in protection.

With the help from trained and certified equipment managers at major colleges and professional levels of football, it is uncommon to see a player participating in the sport of football wearing a helmet that does not fit. At lower levels, such as youth and high school football, you may see a player constantly adjusting their helmets, or helmets constantly falling off after certain plays. In their epidemiological study, Greenhill et al (2016) analyzed concussion injury report data from a nine-year period. They focused on concussion symptoms, duration, as well as helmet parameters. In total, 4,580 concussions were analyzed. Data suggested that athletes with improperly fitted helmets experienced greater rates of drowsiness,

hyperexcitability, and sensitivity to noise. They also experienced on average more symptoms. Overall, athletes with improperly fitted helmet experienced worse symptoms for longer periods than athletes who sustained a concussion with a properly fitted helmet.

Alternatively, Greenhill et al. (2016) also looked at helmet liners and their impacts on concussions. They explained that helmet liner data was included in 3,352 report. 2,690 helmets had an air bladder interior lining, while 662 had a foam or gel lining. Of this data, concussion symptoms lasted longer in athletes with air bladder liners, including sensitivity to light and noise. One suggestion for this made by the authors, was that air leakage from those bladders could result in a helmet that does not fit as properly as it once did.

What Can Still be Done to Help Protect Athletes from Concussions

Much has been done to help prevent athletes from concussions including better helmet technology, better concussion tracking systems, and overall, a greater understanding of concussions themselves. With that being said, concussions are not going away and more needs to be done. One example of this is highlighted in the study done by Breedlove et al. (2018). Their study analyzed current helmet drop tests, and how their results differ from tests done with a facemask attached to the helmet. To clarify, these drop test studies are usually done by The National Operating Committee on Standards for Athletic Equipment, or NOCSAE for short. The current helmet drop tests are performed with helmets that do not include facemasks. In the study by Breedlove et al. (2018), nine helmets were tested including three Riddell SPEED, three Xenith X2E, and three Xenith Epic. Each helmet was a size large, new, and never used in competition. They also were tested with the standard facemask sold with the helmet. In terms of testing, the helmets were fit to a head form and dropped from a tower at velocities and orientations prescribed by NOCSAE. Results showed that helmets with facemasks on them

produced higher scores on the Gadd Severity Index (GSI) in five of six drops at all three velocities than they did on the tests without facemasks. All in all, the study showed that with facemasks on, linear acceleration and GSI were increased. One important thing pointed out by the authors was that the helmets still passed the NOCSAE GSI threshold. The problem though is that these drop tests can help companies with helmet refinement and designs and could misguide designer from making more efficient helmets. Also, if a helmet is close to the threshold for testing, it could theoretically fail with a facemask on, and no one would know. The authors recommended further testing be done with facemasks because they are more accurate, and to prevent these types of mistakes from being made in the future.

In a similar study where, current testing protocol is challenged, Bartch et al. (2012) compared modern football helmets with vintage leather helmets. The aim of this study was to compare head impact doses and head injury risk between the two because modern football helmets are universally believed to be much safer than vintage ones. This study was done with 11 popular modern football helmets meeting NOCSAE standards, as well as two 20th century leather helmets. Each helmet was attached to a headform and impacts tests were done on the front, oblique front, lateral, oblique rear, and rear head. Impacts replicated near and subconcussive head impact doses equivalent to the 95th percentile of on-field collision severity, according to the authors. Bartch et al. (2012) discovered that in many instances, the leather helmets performed as well, or better, than the modern helmets and the protective level was similar between the two types. The authors believe the reason for this is because modern football helmets are built to withstand high-severity doses and protect against fracture and severe brain injury, whereas concussive and subconcussive hits still cause damage. The authors recommended

helmets be designed to protect both types of hits, as well as youth helmet testing needs to rapidly advance.

As stated earlier, the HIT System can be a useful tool in tracking head impact location and accuracy and can help better protect athletes against concussions. The study done by Jadischke et al. (2013) also looked at the HIT System accuracy, and found data to support potential error in some of the HIT data. The authors of this study explained that most HIT testing used a medium helmet on a dummy head model called Hybrid III. The study compared the circumference of the head on the Hybrid III to regular human subjects, and using a skull cap with attached sensors, found that the majority of athletes with similar head circumference to the dummy would use a size large helmet instead of medium. “A medium helmet on the Hybrid III was comparable to the average pressures greater than the 99th percentile volunteer pressure level” (Jadischke, Viano, Dau, King, & McCarthy, 2013). This can cause error in data and is another example of the need for advancement in testing. The HIT System can be a great tool, but still needs to get better in order to better protect athletes.

Summary

Research has shown that currently there are a lot of great ways technology is contributing in a positive manner towards the war against concussions. It has also shown that there are a lot of ways that we can use technology to better protect athletes against concussions. Although there is not one single thing that is out there currently that will prevent an athlete from getting a concussion, doing a number of things the right way can help lower the odds of getting one, or make concussion symptoms less severe. The use of video analysis is currently helping multiple sports spot concussions in real time and gets athletes off the field before they further hurt

themselves. Video analysis can also help leagues spot consistencies in concussion events, and in turn, help them formulate countermeasures.

In the sport of football, the helmet is looked at as the number one protective piece of equipment for athletes against concussions. With that being said, helmet companies are constantly designing the safest product possible by creating new designs and testing out different material. Most current models, regardless of the brand, have very similar protectiveness, even though each one claims to be the best. The importance of proper helmet fit often gets overlooked, but the study done by Greenhill et al. (2016) highlights how improperly fitted helmets can contribute to increased concussion symptoms with longer symptom durations. They also highlighted how helmets with air bladders can contribute to improper fit because of air loss.

There is still a lot that needs to be done to help protect athletes against concussions, and technology can contribute to that. Multiple studies acknowledged the need for better helmet certification testing, better testing methods, as well as continued studies into better material used in helmets. Concussions may never fully be eliminated from sports, but athletes can still be better protected.

Chapter 4

Results, Discussion and Recommendations for Future Research

The purpose of this chapter is to present the results of the review of literature on the effects of technology on reducing the risk of concussions in sports, and how these results align with the purported research questions which guided this synthesis project. In addition, recommendations for future research as it relates to protecting athletes from concussions are presented.

The results of this review of literature revealed many different ways that technology is being used to help protect athletes against concussions. At this point, concussions as a whole are not disappearing from sport, but technological advances in understanding, tracking, and better preventing them in athletes is growing. In the sport of football, concussions are the topic of conversation when it comes to injuries. Helmet design does play a major role in preventing concussions, and continual research and updates to helmet design as well as material used can have a positive effect on player safety. It is also worth reviewing current helmet protocols and updating them more frequently as more information regarding concussions emerges.

Discussion

Interpretations

As part of this literature review, several research questions were posed. The first research question examined what technology was being used currently to help prevent concussions in athletes. In the study done by Lessley et al. (2018) results from video analysis of concussions in the National Football League helped show which positions have been more susceptible to concussions, as well as which plays have been experiencing the most concussions. Reviewing film of concussion events can help identify new trends in how concussions are occurring and can

assist in potential rule changes as well. As the game of football changes, by reviewing film like this, leagues like the NFL can stay on top, or ahead, of concussion countermeasures.

The second research question was, how can current football equipment help protect athletes from concussions? The results showed in multiple studies that it is not only good enough to have proper up-to-date helmets with the right materials, it is also extremely important that those helmets fit properly on the athletes. Rowson et al. (2014) showed in their study that it does in fact matter what helmet you put on your head, as some helmets simply protect better against concussions than others. Greenhill et al. (2016) analyzed concussion data from high school athletes over nine seasons and found that athletes with improperly fitting helmets have an increased risk of concussion severity and duration as opposed to helmets that are properly fitted. They also found that helmets with air bladder linings can make athletes more susceptible to longer concussion duration, which the authors suggested could be from air leakage, leading to improper fitting for an athlete. Using more up-to-date helmets, with different liners such as gel or foam prevents this.

The last research question asked was, what can still be done to help prevent athletes from concussions? After looking at the research, it is evident that although a lot has been done to help protect athletes, there needs to be an effort to continue to make better football helmets, update testing standards, and continue to look for better materials to use in football helmets. In the 2012 study done by Bartsch et al, which compared impact tests for 20th century leather helmets and 21st century modern football helmets, it was shown that at the end of the day, the two types of helmets showed similar protectiveness to near and subconcussive impacts. The authors explained that modern helmets have been made to test well against and withstand high-severity impacts, but the constant lower severity impacts lead to concussions as well, and manufacturers need to

find a way to better protect against both. The authors also suggested a need for advancing testing standards to help protect both types of impacts, especially for youth football helmets. The study done by Breedlove et al. (2018) also suggests a change to testing standards for football helmets. Their study explains that NOCSAE certification tests do not require football helmets to be tested with the facemask on. The helmet itself does change in weight and structure when a facemask is attached, and when tested in NOCSAE-style drop tests, helmets with attached facemasks showed increases in acceleration and severity index. Although there are different styles of facemasks, they should be considered in future testing standards.

In a study relating to material, Nakatsuka & Yamamoto (2014) studied foam layers on the outer shell of the football helmet and found that adding a soft outer layer to a helmet can reduce the force of impact. Similarly, as stated earlier, the study done by Greenhill et al. (2016) also showed that a foam liner could be more beneficial to protecting athletes as opposed to air bladder liners. Both these studies could lead to more studies done on materials such as foam in reducing concussions in athletes.

Implications

Concussion research as a whole is still fairly new, and therefore concussion prevention is still a work in progress. A lot of work has been done to prevent continuous concussions such as certain return to play rules, as well as helmet regulations, and rule changes to help protect the athletes in sports such as football. Studies from this synthesis show some positives of what is currently being done to help stay on top of concussion prevention, such as analyzing plays to see if certain trends or plays in the sport of football are leading to concussions.

One thing that is evident from the synthesis, multiple studies have exposed weaknesses and flaws in the current helmet testing done by the NOCSAE. Currently, helmets are tested to

withstand impacts that lead to skull fractures, but lower impacts can still lead to concussions.

Multiple studies looked at in this synthesis recommend a change in testing standards that could greatly benefit the athletes.

Limitations & Recommendations for Future Research

In reviewing the data based on the effects of technology on reducing the risk of concussions in sports, the following limitations were noted regarding the studies under review. All studies used testing standards in line with NOCSAE helmet testing. This standard of testing appears to be the only one that is widely accepted for helmets and each helmet design must pass this test before it can be used in play. The studies in the synthesis were limited to information that has been collected over a certain period of time and were also limited by the variables examined within the research. Overall, there is still a limited amount of peer reviewed research studies done on helmets and materials, as well as technology that can assist in protecting athletes against concussions.

Based on these limitations and other insights related to the literature the following recommendations for future research should be considered:

1. Helmet testing certifications by the NOCSAE need to be constantly advancing in order to better protect athletes. This means not only testing helmets as they would be worn on the field, but also testing them to withstand both low impacts as well as high impacts.
2. Material used in football helmets need to continue to advance in order to better protect players. This means more studies being done on the benefits of foam or gel line and potentially a better material for the outer shell of the helmet besides hard plastic.
3. Video analysis is a great way to analyze the game of football. It can help leagues such as the NFL make the game safer by spotting trends and making or changing rules to help better protect

athletes. Leagues should continue to build upon video analysis or start to incorporate it in concussion prevention and protection.

4. The importance of proper fitting equipment can help better protect athletes against injuries.

This is easier to do in college and professional level sports where people such as equipment managers are paid to make sure athletes have the right fit for helmet, shoulder pads, cleats, and other protective equipment, but it needs to be emphasized more in high school and youth sports.

5. Can there be an impact number that immediately takes an athlete out of competition to protect them from more unnecessary hits?

Summary

The purpose of this literature review was to determine the effects of technology on reducing the risk of concussions in sports. Delimiting variables were used to do an exhaustive data-based search which yielded thousands of articles. These articles were narrowed down and then systematically used to determine the effects technology has on reducing the risk of concussions in athletes. Research revealed that multiple factors go into helping protect athletes against concussions, especially in the sport of football. In terms of equipment, proper helmet fitting is a great start. It is important to note that even though no helmet right now completely prevents concussions, newer helmet designs better protect against concussion than older ones, so it is important that helmet manufacturers continue to keep upgrading and trying to make the best helmet possible.

Analyzing video and injury reports is a great way to stay on top of concussions and by better understanding how and why they happen, it can be easier to prevent them. Many leagues have added the use of video analysis to help spot concussions. Video analysis is also helping medical staff learn more about concussions and what to look for in athletes during competition.

This can be built upon by not only spotting athletes with potential concussions, but it can also help leagues evaluate concussion causing scenarios and assist them in staying ahead of the injury. Although this type of preventative measure may be expensive, it could be extremely beneficial for high school and college athletics to incorporate this as well.

Further research and advancements in equipment manufacturing, materials used in helmets, as well as helmet testing standards still need to continue. Doing so will only make sports like football safer. Players are becoming bigger, faster, and stronger and sports are constantly transforming. Constant advancement in concussion prevention is needed in equipment and technology in order to stay on top of concussions. This is the best way to help protect athletes so sports participation can continue to grow. Concussions may never disappear from the game, but by making sports safer, it will encourage even more participation, and therefore continue to grow the game.

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Appendix A

Author	Title	Source	Purpose	Methods & Procedures	Analysis	Findings	Recommendations
Adam Bartsch, Edward Benzel, Vincent Miele, and Vikas Prakash	Impact test comparisons of 20 th and 21 st century American football helmets	Journal of Neurosurgery	To compare head impact doses and injury risk with 11 widely used 21 st century American football helmets and 2 early 20 th century leather helmets.	Impact tests were performed in a biomechanics laboratory.	11 current varsity helmets and 2 leather helmets were struck in 5 different positions using helmeted head forms. The impact was similar to that of a concussion and on-par with the 95 th percentile of on-field collision severity.	For many of the impacts, the leather helmets demonstrated head impact doses and injury risk on par with or better than those demonstrated by several of the varsity helmets. Overall, majority of the impacts showed a similar protectiveness profile for leather helmets and modern helmets.	The 21 st century varsity helmets frequently did not provide substantial protective superiority in near- and subconcussive head impacts as compared with leather helmets. -Data supported in this study suggests that the GSI, which is the rating system for helmet protectiveness is not effective. This is because this system rates helmet protectiveness based on the risk of severe skull fracture.

<p>Lessley, David J; Kent, Richard W; Funk, James R; Sherwood, Christopher P; Cormier, Joseph M; Crandall, Jeff R; Arbogast, Kristy B; Myers, Barry S</p>	<p>Video Analysis of Reported Concussion Events in the National Football League During the 2015-2016 and 2016-2017 Season</p>	<p>American Journal of Sports Medicine</p>	<p>The purpose of this study was to review video of reported concussions from NFL games.</p>	<p>Descriptive epidemiologic study.</p>	<p>All reported concussions were reviewed with available video footage, and then categorized based on details of the event.</p>	<p>It was found that cornerbacks sustained the most concussions, followed by receivers, then then linebackers, then offensive linemen. Half of concussions occurred during a passing play.</p>	<p>There is a need for expanded evaluation for concussion countermeasures.</p>
<p>Steven Rowson, Stefan M. Duma, Richard M. Greenwald, Jonathan G. Beckwith, Jeffrey J. Chu, Kevin M. Guskiewicz, Jason P. Mihalik,</p>	<p>Can helmet design reduce the risk of concussion in football?</p>	<p>Journal of Neurosurgery</p>	<p>The purpose of this article was to explore the question if helmet design can reduce the incidence of concussion.</p>	<p>Quantitative analysis. 1833 football players were equipped with a helmet-mounted accelerometer and data was measured from 2005-2010.</p>	<p>Data was collected from 1833 players from 8 collegiate football teams. Head impact exposure data from all games and practices that players participated in was analyzed.</p>	<p>1,281,444 head impacts were recorded, 64 concussions were diagnosed. 322,725 head impacts were recorded to players wearing Riddell VSR4</p>	<p>Concussions can in fact be reduced based on what helmet you are wearing. Helmet design should be optimized to reduce head acceleration.</p>

<p>Joseph J. Crisco, Bethany J. Wilcox, Thomas W. McAllister, Arthur C. Maerlender, Steven P. Broglio, Brock Schnebel, Scott Anderson, and P. Gunnar Brolinson</p>						<p>helmets, including 27 concussions. 958,719 impacts were recorded to players wearing Riddell revolution helmets, including 37 concussions.</p> <p>Players in VSR4 helmets sustained 8.37 concussions every 100,000 head impacts, while players in Revolution helmets sustained 3.86 concussions per 100,000 head</p>	
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						impacts. A lower % of players in revolution helmets sustained concussions compared to players in VSR4 helmets, despite players in revolution helmets experiencing more impacts per season.	
Andrew Gardner, Kenneth L. Quarrie, Grant L. Iverson	The Epidemiology of Sport-Related Concussion: What the Rehabilitation Clinician Needs to Know	Journal of Orthopedic & Sports Physical Therapy	The purpose of this article is to summarize key concepts related to sport-related concussions.	Qualitative research	The authors used epidemiological studies relating to concussions, as well as reviewed incident rates of sport-related concussions in high school athletes,	Protective headgear studies need more investigation, but the general opinion is that headgear provides little to no effect on preventing	Headgear in general may be giving athletes a false sense of security Importance of concussion tracking systems; In 2012, The Ivy League and Big Ten established a combined surveillance system where

					National Hockey League athletes, as well as the National Football League athletes.	concussions. Wearing headgear may encourage players to play more aggressively, because they feel more protected, placing them at a greater risk of injury. Collegiate football players who suffered a concussion were also more likely to suffer another one in the same season.	athletic trainer's complete data collection and enter it online for each concussion event.
Christy L. Collins, Lara B. McKenzie, Amy K. Ferketich, Rebecca	Concussion Characteristics in High School Football by Helmet Age/Recondition Status,	The American Journal of Sports Medicine	Investigate whether high school football concussion characteristics vary by	Epidemiologic study	Collected high school football concussion and helmet data from years 2008-2009 through	Overall, for new and reconditioned helmets, the most common helmet	Although data showed no real difference between the helmets at the time, doing research like this

Andrisge, Huiyun Ziang, R. Dawn Comstock	Manufacturer, and Model		helmet age/recondition status, manufacturer, and model.		2012-2013 as part of the National High School Sports-Related Injury Surveillance Study.	manufacturers and models on the market provide similar protection.	is important to help make sure newer helmets and designs are safe and to analyze differences in helmet protection.
Ramsey W. Fisher	Evaluation a “Concussion Clause”: Why the NFL’s Assumption of Risk Defense Fares No Better as Time Goes On	Vanderbilt Journal of Entertainment and Technology	The purpose of this article is to explore the NFL concussion litigation and its future.	Qualitative research	Assumption of risk, concussion clause, and ethics are all touched upon	“99% of studied retired NFL players’ brains show signs of CTE” Although the risk of concussion in the NFL is now known better, a clause would further help the NFL avoid liability.	For the NFL, it may not be so much as technology helping them with concussions. If a clause is in place and players assume all risk, they can avoid future liability.
Michael J McNamee, Bradley Partridge, Lynley Anderson	Concussion in Sport: Conceptual and Ethical Issues	Kinesiology Review	The purpose of this article is to discuss the philosophical, bioethical, and sport	Qualitative research	Conceptual and ethical issues are discussed revolving around athletes and	The exact definition of a concussion and how to treat it, as well as when to return to	A large amount of ethical issues revolves around concussions. There is still a lack of agreement on the nature of a

			<p>ethical perspectives revolving around concussions.</p>		<p>concussions. Issues discussed include the true definition of a concussion, return to play following a concussion, diagnosing a concussion, and the ethics regarding concussions in children.</p>	<p>play is not entirely agreed upon. The awareness of the seriousness of concussions is on the rise. All involved in sport need to be made more aware of the necessary protocols for head injuries. The long-term effects of concussions are still not entirely understood Ethical issues will continue to surround athletes with</p>	<p>traumatic brain injury.</p>
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						head injuries.	
Dustin A. Greenhill, Paul Navo, Joseph Torg, R. Dawn Comstock, Barry P. Boden	Inadequate Helmet Fit Increases Concussion Severity in American High School Football Players	Sage Publication Journals	The purpose of this article is to investigate the relationship between improperly fitted helmets on high school athletes and the severity of a concussion.	Quantitative	Concussion data from high school athletes over a 9-year period was analyzed along with symptoms, duration, and helmet fit.	Athletes who suffered a concussion with a helmet that did not fit properly, determined by an athletic trainer, had had more symptoms, as well as athletes that had helmets lined with an air bladder.	The padding inside the helmet is just as important as the fit. Air bladders are not as safe as foam and gel interior.
Gavin A Davis, Michael Makdissi, Paul Bloomfield , Patrick Clifton, Ruben J Echemedia , Ean Cian Falvey, Gordon	International Study of Video Review of Concussion in Professional Sports	British Journal of Sports Medicine	The purpose of this study was to assess current practices related to video review of concussion in professional sports	Qualitative research. Questionnaire was issued regarding video analysis and concussions.	A questionnaire was sent out to senior medical advisers and chief medical officers from different leagues including the AFL, CA, MLB, NFL, NHL, and	6 of the 7 sports are currently using live video review to assist with concussion management , the only one not using it being the MLB.	In-game video analysis is assisting leagues in spotting concussions in athletes. In particular, the NFL uses video review to spot concussions in-game, and those spotters can call down to the

<p>Ward Fuller, Gary Green, Peter Rex Harcourt, Thomas Hill, Nathan McGuirk, William Meeuwisse, John W Orchard, Martin Raftery, Allen K Sills, Garry S Solomon, Alex Valadka, Paul McCrory</p>					<p>WR. The questionnaire touched upon video review and how it relates to concussions assessment.</p>		<p>sideline and pull players from games. The NFL also uses video review for educational purposes for medical staff.</p>
<p>Austin S. Nakatsuka, Loren G Yamamoto</p>	<p>External Foam Layers to Football Helmets Reduce Head Impact Severity</p>	<p>Hawai'i Journal of Medicine & Public Health</p>	<p>Since current football helmet design currently has a hard exterior and foam interior, the purpose of this study is</p>	<p>Experimental study. A commercial helmet with built-in Head Impact Telemetry System (HITS) made by</p>	<p>The helmet was struck with another helmet 9 separate times, each time altering the thickness of foam layer.</p>	<p>Adding a foam layer to the exterior of a football helmet's surface reduces the impact</p>	<p>There are caps to put over helmets to provide another foam layer of protection but are used in practice and are not very popular.</p>

			to examine the impact reduction potential on external foam.	Riddell was used in the study to record hit to normal and modified helmet exteriors.		severity and injury potential for concussion.	
Katherine M. Breedlove, Evan L. Breedlove, Thomas G. Bowman, Ellen M. Arruda	The Effect of Football Helmet Facemasks on Impact Behavior during Linear Drop Tests	Journal of Biomechanics	Football helmet certification tests are performed without the facemask attached to the helmet. The facemask does however add mass and stiffness when attached, so the authors wanted to see how adding a facemask to the tests would change the data.	An experimental study was done using 9 helmets with facemasks attached.	Helmets had facemasks were attached and dropped using NOCSAE prescribed standards for drop towers and velocities.	All helmets still passed the NOCSAE GSI thresholds with facemasks attached, but did show evidence that facemasks being attached did increase GSI and peak linear acceleration in NOCSAE-style impact tests.	Authors believe facemasks should be attached for NOCSAE certification tests. Although each helmet passed certification with facemasks on, tests should mimic on-field usage, and facemasks are worn on field when players wear their helmets.
Jadischke, Ron; Viano, David C;	On the Accuracy of the Head Impact	Journal of Biomechanics	The purpose of this study is to measure the accuracy	Experimental study.	A skull cap equipped with sensors was used to	Typically, HIT testing uses a medium	Most studies of HIT used a medium helmet which is too tight

<p>King, Albert I; McCarthy, Joe (2013)</p>	<p>Telemetry (HIT) System Used in Football Helmets</p>		<p>of the HIT for individual impacts on football helmets.</p>		<p>measure pressure between the head of football players and their helmets. This was then compared to the Hybrid III dummy head wearing a large helmet, compared to the medium helmet, which was generally used for testing the HIT system.</p>	<p>helmet. According to the research though. The head circumference of the dummy would equate to a normal human needing to wear a large helmet. A medium helmet on the hybrid III produced average pressures greater than the 99th percentile volunteer pressure level.</p>	<p>for the Hybrid III dummy head and is not correctly representing how most players wear their helmets on field. Therefore, there can be error in individual impact data making it less accurate.</p>
<p>Campbell, Kody R; Marshall, Stephen W; Luck, Jason F;</p>	<p>Head Impact Telemetry System's Video-based Impact Detection and</p>	<p>Journal of the American College of Sports Medicine</p>	<p>The purpose of the study was to analyze the HIT system's impact</p>		<p>Participants were selected from a single high school football team. Data was</p>	<p>1500 player-plays were reviewed and 496 impacts were identified on</p>	<p>There is a continued need for impacts and impact locations to be accurately</p>

<p>Pinton, Gianmarco F; Stitzel, Joel D; Boone, Joshua S; Guskiewicz, Kevin M; Mihalik, Jason P (2020)</p>	<p>Location Accuracy.</p>		<p>detection and location measurement accuracy.</p>		<p>taken from the 2017 season. Each participant wore a Riddell helmet with a built in HIT system. Video was then reviewed of impact during special teams plays and documented times when a participant experienced impact that could trigger HIT data collection.</p>	<p>video. Ultimately, it was estimate that the HIT system’s impact-filtering algorithm correctly categorized 70% of 317 impacts as true impact events.</p>	<p>measured. He HIT system is useful for estimating population-based impact locations distribution for special teams plays, which is what they were looking for.</p>
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