Simulating Helmet to Ground Impact in the NFL

The Effects of Helmet Advancements on Concussion Rates in the NFL

A Thesis Prospectus
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

A lot of concussions occur in the NFL. In fact, there were 213 concussions suffered during the NFL preseason and regular season in 2022, and 219 in 2023 (Reed, 2024). Football is widely considered the most dangerous sport regarding head injuries in the United States, and for good reason. This claim is supported by evidence showing that football had the second highest number of head injuries caused by sports treated in U.S. hospital emergency rooms after cycling (Agarwal et al., 2024). There were 64,411 instances amongst cyclists and 51,892 amongst football players, yet there are far more cyclists than football players. It is not uncommon for parents to prohibit their children from playing football due to concerns of head injuries, and players and parents agree that concussion education is important for all football players (Newall & Sawyer, 2024).

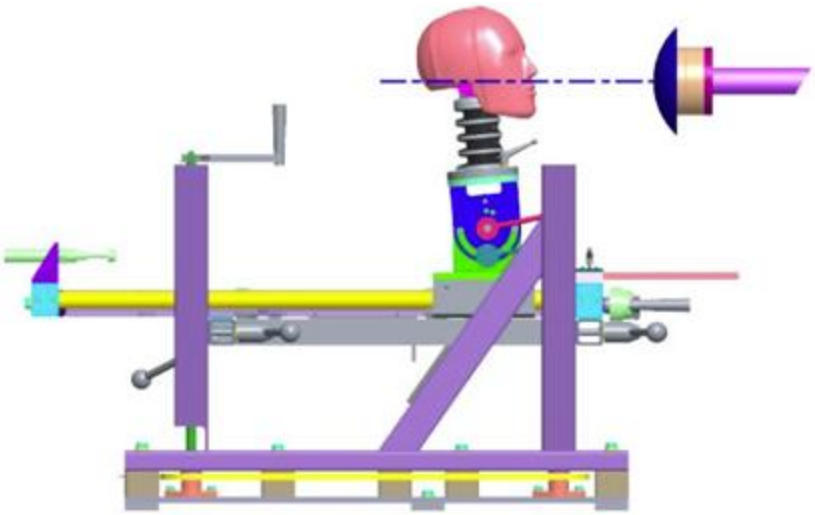
With the goal of making football safer, the NFL first made helmets mandatory in 1943 (MacDonald, 2020). Headgear at that time consisted of a hardened leather exterior with ventilation, padding, and earholes (Solomon, 2023). Around the same time, John T. Riddell was developing the first plastic helmet, and by 1949 the NFL had officially adopted it (Crow, 2021). Helmets have continually developed since their introduction. In the mid-1950s, the single face bar was introduced. Throughout the 1960s players' facemasks began expanding to two and three bars. This change reduced injuries such as knocked-out teeth, broken noses, and gouged eyes. It also, however, led to a false sense of fearlessness. This made players more likely to lead with their head (rather than their shoulder) when tackling. Helmet development continued through the 70's and by the 1980s Riddell had created the classic helmet silhouette we recognize today (circular earhole, rounded dome). The modern helmets used in the NFL today largely resemble the same models used in the 1980s, but they are stronger, lighter, and feature better designed

padding systems to reduce injuries. Because our understanding of the risks of concussions has improved at a rapid rate in recent years, improvements to the NFL helmet design have increased. Since annual helmet testing began in 2015, the rate of helmet model improvement has become nine times faster (*Helmet innovation*, 2022). This reflects a shared recognition among players, coaches, fans, helmet designers, and the NFL itself that head injuries are a serious issue in the sport.

I will be pursuing a technical research topic through my Mechanical Engineering Design Capstone. This research will involve creating a device to test helmet-to-ground impacts, one of the leading causes of concussions in the NFL. Along with this technical work, I will use an STS framework to explore the effects that helmet development has had on concussion rates in the NFL as well as examine how the league's perspective on concussions has evolved as knowledge of the subject has expanded.

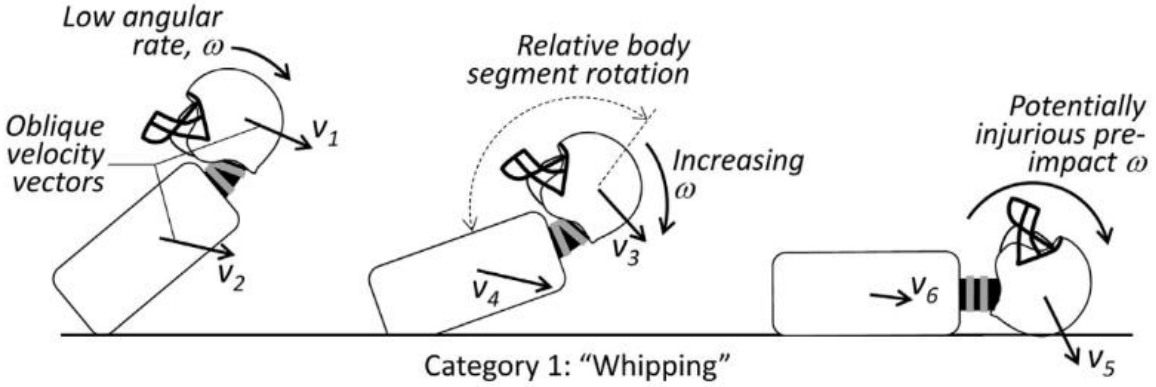
Technical Topic

Approximately 20% of concussions in the National Football League are caused by helmet-to-ground impacts (Lessley et al., 2018). The current approach to improving helmet designs relies on data from impact testing, though it currently uses data only from helmet-to-helmet tests. Devices for helmet-to-helmet impact testing are more widely available, affordable, and easier to use than any existing helmet-to-ground testing devices. A typical helmet-to-helmet impact testing device setup is depicted below (*Helmet test*, 2019).



While it is not shown in the image, it is important to note that during testing the dummy head is wearing a football helmet. The apparatus shown can position the head at different orientations to simulate impacts to different sides of the head. These linear impact testing devices are great at simulating helmet-to-helmet impacts and have led to further development of football helmets, but they fail to represent the forces a player's head would experience upon impact with the ground. The primary difference between the two types of impacts is that in a helmet-to-helmet situation, the players' heads are usually in a more stable position than in helmet-to-ground situations. The reason for this is that when a player's body hits the ground, their head whips backwards which causes an angular acceleration paired with the existing linear velocity vector. Another critical difference between helmet-to-helmet impacts and helmet-to-ground impacts is that the vertical component of the velocity vector will be completely stopped by the ground and significant rebound can occur in helmet-to-ground situations (Joodaki, 2019). Designing a device that simulates the characteristics of helmet-to-ground impacts would be extremely beneficial for further development of player helmets as it would give helmet manufacturers more data to account for.

To do this, a prototype of the testing machine will be designed and created so that scientific knowledge on the mechanics of helmet-to-ground impacts continues to expand. In designing this device, the most important features will be its ability to simulate the pre-impact linear and rotational velocities of the head over a range of values representative of typical helmet-to-ground impacts. The figure below shows an overview of the kinematics of helmet-to-ground impacts (Kent, 2020).



Important to note are both the oblique velocity vectors and the angular velocity of the head. To replicate these velocity vectors with an affordable repeatable device we have designed a curved track that the dummy will slide down and eventually release from. Upon release the dummy will only have a horizontal velocity component but it will be released from different heights above the ground. The release height will give the dummy time to fall, creating the vertical component of the velocity that we need. When released, the dummy will be oriented at an angle from the ground like the depiction of the dummy on the left in the figure above. When the torso of the dummy contacts the ground, the impact will initiate the rotational velocity we need. What makes our design beneficial to the field is the fact that the device will be easy to use and inexpensive (powered completely by gravity). The data our device gives will help improve helmet designs for the NFL which will in turn help reduce concussions and brain health league wide.

STS Topic

In my thesis, in order to understand the extent to which our technical research will affect society, I am going to explore whether or not the development of helmets has led to a reduction in head injuries. To do this, I will need to compare modern NFL helmets to past models. I will also look at how societies ever-changing understanding of brain injuries has affected historical head injury data in the NFL. Specifically, I will use the framework of technological momentum to discuss these topics (Hughes, 1987).

Concussions themselves have been a growing concern since the early 1900s (*A brief history*, 2024). The NFL did not start formally recognizing concussions until 1994 when they created the Mild Traumatic Brain Injury (MTBI) committee (Strom, 2020). At this time, the league considered knee injuries, as well as drug, steroid, and alcohol use as "far greater" problems than brain injuries (Ezell, 2013). The NFL's commissioners, team owners, and MTBI members have downplayed the significance of brain injuries caused by the sport multiple times since 1994. Since this time players have become more open about citing concussions as a reason for retirement, and retired players started mentioning football as the reason for their cognitive problems such as dementia. The overall awareness of concussions as a major issue for the league has drastically risen in recent years, especially after research has shown that repeated head impacts can lead to chronic traumatic encephalopathy (CTE). Players are more likely to be taken out or held out from playing due to concussions than ever before. The league no longer denies the existence of a problem but rather advertises what they are actively doing to try to solve the issue. In 2015, for the first time, the NFL acknowledged the serious long-term health effects of concussions by releasing a poster to the players. The poster disclosed more information on the effects of repeated head trauma than prior information that had been released to players. (*Head to*

head, 2019). Society's increased focus on brain health has led to more rapid development and innovation for football helmets.

Since 1996 concussion rates in the NFL have slowly declined, but not by much (Casson, 2010). In recent years concussions rates have started to stagnate, however. For example, the 2022 season saw an 18% increase in concussions suffered during regular season games compared to 2021. It is hard to say whether this is because the concussion problem is getting worse, or because the definition of a concussion has become more definitive. Either way, the league has become more cautious and conservative in its evaluation and diagnoses of concussions (Seifert, 2023). Being a business corporation, the NFL ultimately wants to make money. For this reason, they need to listen to their fans. As conversations among fans concerning head injuries has increased, so has the strictness of the NFL's concussion protocol. However, the league still has strides to make. For example, NFL doctors still say that the league is not a direct contributor to CTE (*Dangers of concussions,* 2023).

These human and societal factors are directly affecting the further development of football helmets. In fact, the invention and entire development of the football helmet is a perfect example of technological momentum. Helmets were first invented when players were concerned for the safety of their heads. Through the years, players, coaches, NFL executives, fans, and scientists have drastically affected the development and style of the helmet's design. For example, NFL players do not always choose to wear the safest helmet, they often choose based on which helmet is the most stylish. Competition amongst helmet companies continues to drive innovations in design. And, most of all, the increasing awareness and emphasis on brain health nationwide has and will continue to be the primary driver in further football helmet innovation.

The more dangerous society views football, the more the NFL helmet will have to change to help protect its players.

Research Questions and Methods

The research question that I will attempt to answer in my thesis is as follows: How has the development of football helmets affected brain injuries for NFL players? To answer this question, I will analyze whether helmet advancements have made the game safer, and whether or not the game was safer before helmets were used.

In order to retrieve data and accurate information to address this question, my plan employs four different research techniques. Firstly, I am going to find articles and agency reports from helmet manufacturers and create a timeline for when new helmet models were released (Kraus, 2023). Paired with this timeline, I will describe the changes introduced with each newer helmet model and the reason for those changes. Secondly, I will create a timeline that maps concussion rates in the NFL over the same time period. To find this data I will look at previously published literature, and concussion counts year to year. In this section I will also discuss how the rising awareness around brain injuries may be the cause of increased rates. Thirdly, I will create a timeline of the rule changes that the NFL has passed for both the way teams practice and play games. With these three parallel timelines, I will be able to map concussion rates in comparison to different events and determine what exactly causes decreases or increases in concussion rates, and more specifically, whether or not helmet advancements are the cause. Lastly, I will briefly compare brain injury rates in football before helmets were worn, and brain injury rates in the National Rugby League. This will help assess whether wearing helmets is beneficial for football players. In analyzing this data, I will look at it through the lens of how

technology and society affect each other, as well as the scope of society newer technologies affect.

Conclusion

By the end of the Spring semester a fully functional helmet-to-ground test device will be produced. It will successfully simulate the pre-impact conditions of a helmet-to-ground impact by replicating the pre-impact linear and angular velocity vectors. This more affordable testing device will help scientists conduct more research on helmet-to-ground impacts. The research conducted will ultimately provide more information for helmet designers to create safer football helmets for not only NFL players, but football players at every level of the game.

As the STS topic addresses, through thorough data collection with four methods of research, I hope to discover how the advancements made in football helmet designs has affected players' brain injury rates in the NFL. Depending on my findings, this research could be useful for NFL rule makers, helmet designers, players, coaches, and parents to make more informed decisions.

References

A brief history of concussion as a public health issue. (2024). Concussion Alliance. https://www.concussionalliance.org/history-of-concussion

Agarwal, N., Thakkar, R., & Than, K. (2024, April 11). *Sports-related head injury*. American Association of Neurological Surgeons. https://www.aans.org/patients/conditions-treatments/sports-related-head-injury/

Casson, I. R., Viano, D. C., Powell, J. W., & Pellman, E. J. (2010). Twelve years of National Football League concussion data. *Sports Health, 2*(6), 471–483. https://doi.org/10.1177/1941738110383963

Crow, K. (2021, August 27). *The history of football helmets*. Xenith. https://xenith.com/blog/the-history-of-football-helmets?srsltid=AfmBOor4BpJo20H8vo3TXhN4WXCpOD1ovR0-b4u2YLuI7KHNkegbi8pO

Dangers of concussions in the NFL. (2023). Pro Athlete Law Group. https://proathletelawgroup.com/dangers-of-concussions-in-the-nfl/#:~:text=Chronic%20Traumatic%20Encephalopathy%20(CTE)%20is,eventually%20kill%20the%20nerve%20cells

Ezell, L. (2013, October 8). *Timeline: The NFL's concussion crisis*. FRONTLINE.https://www.pbs.org/wgbh/pages/frontline/sports/league-of-denial/timeline-the-nfls-concussion-crisis/

Head to head: The National Football League & brain injury. (2019). NYU Langone Health, Division of Medical Ethics. https://med.nyu.edu/departments-institutes/population-health/divisions-sections-centers/medical-ethics/education/high-school-bioethics-project/learning-scenarios/the-nfl-brain-injury#:~:text=In%202015%2C%20the%20NFL%20released,term%20harm%20that%20concussions%20cause

Helmet innovation: More and better choices, fewer concussions. (2022, September 16). NFL

Player Health and Safety. https://www.nfl.com/playerhealthandsafety/equipment-and-innovation/engineering-technology/helmet-innovation-more-and-better-choices-fewer-concussions#:~:text=The%20rate%20of%20improvement%20of,from%20which%20players%20can%20choose

Helmet test protocol. (2019, September 11). Biomechanics Consulting & Research, LLC (Biocore). chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://static.www.nfl.com/image/upload/v1597314821/league/x1555pmeldebfym2qwky.pdf

Hughes, Thomas P. (1987). The Evolution of Large Technological Systems. In W. Bijker, T. P. Hughes, and T. Pinch (Eds.), *The Social Construction of Technological Systems* (pp. 45 76). MIT Press.

Joodaki, H., Bailey, A., Lessley, D., Funk, J., Sherwood, C., Crandall, J. (May 6, 2019). Relative Motion Between the Helmet and the Head in Football Impact Test. *ASME. J Biomech Eng.* 141(8): 081006. https://doi.org/10.1115/1.4043038

Kent, R., Forman, J., Bailey, A. M., Funk, J., Sherwood, C., Crandall, J., Arbogast, K. B., Myers, B. (2020). The biomechanics of concussive helmet-to-ground impacts in the National Football league. *Journal of Biomechanics, 99*, 0021-9290. https://www.sciencedirect.com/science/article/pii/S0021929019308085?casa_token=NK1

Kraus, H. (2023, April 28). *The evolution of NFL helmets*. Prezi. https://prezi.com/p/boaa3arxmqsd/the-evolution-of-nfl-helmets/

Lessley, D. J., Kent, R. W., Funk, J. R., Sherwood, C. P., Cormier, J. M., Crandall, J. R., Arbogast, K. B., & Myers, B. S. (2018). Video analysis of reported concussion events in the National Football League during the 2015-2016 and 2016-2017 seasons. *The American Journal of Sports Medicine, 46*(14), 3502–3510.https://pubmed.ncbi.nlm.nih.

gov/30398897/

MacDonald, F. (2020, April 10). *History of the football helmet*. Atavus. https://atavus.com/history-of-the-football-helmet/

Reed, T. (2024, February 2). *NFL reports lower-body injuries down, concussions up in 2023 season*. The Athletic. https://www.nytimes.com/athletic/5245956/2024/02/02/nfl-concussions-lower-body-injuries/

Newall, M., & Sawyer, J. (2024, February 8). *Majority of parents would let their children play tackle football if they wanted to*. Ipsos. https://www.ipsos.com/en-us/majority-parents-would-let-their-children-play-tackle-football-if-they-wanted#:~:text=Just%20one%20in%20five%20Americans,to%20participate%20in%20tackle%20football

Seifert, K. (2023, February 3). *NFL says regular-season concussions increased 18% in 2022*. ESPN. https://www.espn.com/nfl/story/_/id/35582897/nfl-says-regular-season-concussions-increased-18-2022

Solomon, R. (2023, August 28). *How football helmets are made*. ProQuip Inc. https://proquipinc.com/how-football-helmets-are-made/

Strom, P. (2020, January 25). *Concussion history: The NFL's MTBI committee 1994*. Strom Law Firm. https://stromlaw.com/concussion-history-the-nfls-mtbi-committee-1994/