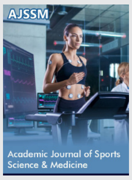

ISSN: 2998-2650

Academic Journal of Sports Science & Medicine

DOI: 10.33552/AJSSM.2026.03.000558

Iris Publishers

Short Communication

Simulation-Based Design and Analysis of Sports Helmet in Order to Decrease Brain Injuries

MF Horstemeyer*

Department of Engineering, University of Liberty, USA

***Corresponding author:** MF Horstemeyer, Department of Engineering, University of Liberty, USA

Received Date: January 09, 2026

Published Date: January 14, 2026

Introduction

Simulation based analysis has helped gather knowledge of the human body in recent years [1-4], but although its inclusion into sports is in its infancy stage, can be transformational as it has been for the largest market industries (automotive, etc.), defense programs (planes, rockets, missiles, etc.), and energy fields (nuclear, petroleum, etc.). Computational modelling simply needs to start influencing sports to a greater extent to make sports safer. Because medical doctors try to clinically analyze cause-effect relationships of a particular sports-related injury, they need tools that help provide the best information for a better prognosis. Historically medical practitioners have leaned on empirical evidence to make prognostic decisions. Although this has tremendously helped improve health and recovery from injury in sports, experimental data alone limits a doctor's knowledge. Multiscale computational methods such as finite element methods for solids, finite difference methods for fluids, and discrete particle methods for lower length scale entities can provide insight and accuracy in which experiments just have not been able to provide. Because we cannot experiment on human subjects to understand the cause-effect relationships of human blunt impacts, empirical methods are limited, although some have recently just started to use computational tools in medical clinical practice [5].

Since the advent of high-performance computing in the 1960's, numerical simulation codes have developed to be very important in failure analysis of engineered structures. In terms of revenue, the global finite element market alone was $4.1 billion in 2020 and is expected to reach $11 billion by 2030 expanding at a 10% rate over the 10 years (Transparency Market Research, 2024) [6]. Some of this increased growth will relate to human health and sports as well, but finite element analysis is not the only computational tool. Artificial Intelligence (AI) and Machine Learning (ML) computational tools will also come into use that will expand the applicability, knowledge base, and usage. And this is just the tip of the iceberg. Let us consider a simulation-based design of football helmets as an example, although similar arguments could be made for other sports' helmets: baseball, equestrian, hockey, lacrosse, etc. First, one must determine the objectives, constraints, and variables in the design of the helmet (c.f. Johnson et al., 2016 [7] for the design of a football helmet facemask). One objective is to minimize brain damage as per the multiscale modelling of Prabhu and Horstemeyer (2021), which contrasts the historical objective of minimizing human skull fracture [8]. Because minimizing skull fracture has been the objective over the years of football helmets, there has been a continuing problem with concussions and Chronic Traumatic Encephalopathy (CTE). Recently, Reynolds (2023) [9] reviewed an article in Nature Communications [10] that showed out of 631 male brain donors who had played football that 72% of them incurred some sort of brain damage. The football players played on average 12 years of football, and they died with an average age of 60 years of age. Compare that report with Mez et al. (2017) [11] who analyzed 112 deceased football players' brains and found that 111 had CTE. Certainly, these researchers result argue that the main objective of a football helmet should be to minimize brain damage. In doing so, the author believes that skull fracture would be subsumed in the design. Hence, when running the simulation-based design, one must include a brain damage model [12] into their simulation software code in order to minimize the damage.

Besides design objectives, the design constraints need to be defined before the simulations take place. The design constraints are typically defined by the particular sport. For a football helmet, different constraints exist: the outer size limit, attractiveness to the players, NOCSAE [13] certification requirements, NFL testing conditions [14], and costs can be considered constraints on the design. Some of the design constraints arise from the NFL, collegiate sports, etc. but others come directly from the company designing and manufacturing the helmet. Once a simulation is conducted, the constraints will determine in a binary fashion if the new design results that decreased brain damage would be admissible or not. If the simulation were not admissible, then another iteration of the design would be required to increase brain damage within the constraint(s) that was violated. If a constraint were not broached, then the simulations would continue to decrease the brain damage towards the lowest brain damage possible.

Another component of a simulation-based design is that of the design variables, which include each of the features that can vary like the shell thickness, shell material, liner thickness, liner material, topology of liner, type and material of facemask, type and material of chin cup, etc. Since any of these design variables can change, it is best to parameterize each of these variables in the simulations allowing for computational efficiency. For example, several thousand simulations were run when optimizing the facemask of Johnson et al. (2016). Instead of employing thousands of expensive high performance computing simulations, one can employ the use of AI, ML, or metamodel algorithms and using the finite element simulation results as the database for the quicker running computations like Fang et al. (2005) [14] accomplished for car crash simulations.

Let us now assume that our design worked, and we already manufactured the football helmet that was optimally designed to decrease brain damage. Twenty-two different football players on the field would be wearing the safest football helmet now based on a simulation-based strategy that has been used millions of times for different engineering applications like those of car impacts, planes crashing, bombs blowing up, etc. Hence, our confidence is up related to the reliability of the helmet and the previous simulations. But the simulation results can be used for something more: data for real-time use during a game. Let's imagine that we have a microcomputer within the helmet communicating with the sideline computer that synchronized the simulation data together. Then, on every play, a medical doctor/trainer on the sideline can immediately see the data from the current impacts of each play for each player and decide if a player received a CTE or concussive damage level or not. Hence, this determination of potential brain damage is not subjective but objective related to the players history and the current play; if a player had previous concussive or CTE level impacts but a lower impact level during the play, then the synchronized data might show the doctor/trainer to take the player out. On the other hand, a player with no CTE or concussive damage level impacts, might incur a much larger impact during a play and still be able to play on. Hence, the history effects can be included into the simulation-based design helmet. Although this might frustrate coaches at the time, it will potentially save the player's brain or, at least, extend their playing career.

In conclusion, simulation-based design and in-game analysis for football games can reach the practicability that is experienced in different industries like the automotive, defense, construction, and energy sectors. When it does, football will be safer for players. However, stakeholders and funding agents need to infuse support for such an endeavour. The return-on-investment of using simulations compared to an industry that does not include simulations typically is about eight times, so it is a safer and more lucrative position to invest in such helmet research and development. Furthermore, one must consider the collateral positive effects of using the simulation-based approaches to other sports such as hockey, baseball, equestrian, etc. given the capability that we are at as a society today.

Acknowledgement

None.

Conflict of Interest

No conflict of interest.

References

1. Quarteroni A, Lassila T, Rossi S, Ruiz-Baier R (2017) Integrated heart-coupling multiscale and multiphysics models for the simulation of the cardiac function. Computer Methods in Applied Mechanics and Engineering 314: 345-407.
2. Bertucci R, Prabhu R, Horstemeyer MF, Mao Y, Gilbrech R, et al. (2018) An anatomically-relevant computational model for primary blast effects on the human lower extremity. Journal of Mechanics in Medicine and Biology 18(5): 1850057.
3. Prabhu R, Horstemeyer MF (2021) Multiscale Biomechanical Modeling of the Brain, Academic Press.
4. Buccino F, Colombo C, Vergani LM (2021) A review on multiscale bone damage: From the clinical to the research perspective. Materials 14(5): 1240.
5. Lytton WW, Arle J, Bobashev G, Ji S, Klassen TL, et al. (2017) Multiscale modeling in the clinic: diseases of the brain and nervous system. Brain Inform 4(4): 219-230.
6. Transparency Market Research (2024) State Tower, Albany, New York.
7. Johnson KL, Chowdhury S, Lawrimore WB, Mao Y, Mehmani A, et al. (2016) Constrained topological optimization of a football helmet facemask based on brain response. Materials & Design 111: 108-118.
8. Levy ML, Ozgur BM, Berry C, Aryan HE, Apuzzo ML (2004) Birth and evolution of the football helmet. Neurosurgery 55(3): 656-661.
9. Reynolds S (2023) How football raises the risk for chronic traumatic encephalopathy. NIH Research Matters.
10. Daneshvar DH, Nair ES, Baucom ZH, Rasch A, Abdo Mohammadi B, et al. (2023) Leveraging football accelerometer data to quantify associations between repetitive head impacts and chronic traumatic encephalopathy in males. Nat Commu 14(1): 3470.
11. Mez J, DH Daneshvar, PT Kiernan, B Abdolmohammadi, VE Alvarez, et al. (2017) Clinicopathological evaluation of chronic traumatic encephalopathy in players of American football. JAMA 318(4): 360-370.
12. Horstemeyer MF, Berthelson PR, Moore J, Persons AK, Dobbins A, et al. (2019) A mechanical brain damage framework used to model abnormal brain tau protein accumulations of National Football League players. Ann Biomed Eng 47(9): 1873-1888.

13. Hodgson VR (1969) NOCSAE: A Program to Reduce Serious Injuries in Athletics. In Sports Safety II, Proceedings of the National Sports Safety Conference PP: 90.

14. Dymek M, Ptak M, Fernandes FA (2022) Design and virtual testing of American football helmets–A review. Archives of Computational Methods in Engineering 29(3): 1277-1289.

15. Fang H, Solanki K, Horstemeyer MF (2005) Numerical simulations of multiple vehicle crashes and multidisciplinary crashworthiness optimization. International Journal of Crashworthiness 10(2): 161-172.