A novel soccer headband design to increase impact absorption in head-to-head collisions

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***Abstract*— Soccer is a contact sport with one of the highest rates of concussions. Players can choose to wear protective headbands that absorb impact during head-to-head collisions and reduce concussion risk. Current commercial headband models are commonly created using a single layer of energy-absorbing polymeric foam. In this study, we propose a novel two-layer headband design that integrates an inner layer of expanded polystyrene (EPS) and an outer layer of expanded polypropylene (EPP) to increase impact absorption during head-to-head collisions. This novel two-layer headband design was evaluated alongside two single-layer headbands (one fully-EPS-based and one fully-EPP-based headband) for comparative purposes. Each of the three headbands was fitted to a human skull model and simulated in a realistic head-to-head collision by using finite element analysis. The novel headband design was the most effective at reducing peak linear acceleration and peak von Mises stress of the skull during the collision, indicating its superior ability to absorb impact. This study demonstrates the viability of a novel two-layer protective headband that may better protect soccer players from concussive impacts.**

I. Introduction

Concussions account for nearly 22% of all soccer injuries [1]. The majority of concussions in soccer are caused by head-to-head collisions between two players. However, unlike other contact sports such as American football or hockey, protective headgear is not mandated in soccer. FIFA, the international governing body for soccer, outlines in Law 4 of its rulebook that “headgear made of soft, lightweight padded material is permitted,” but not mandated. Although the majority of professional and recreational soccer players choose not to wear any protective headgear, some players choose to wear protective headgear to reduce concussion risk during head-to-head collisions. Several protective headgear models based on padded headband designs are commercially available [2,3]. Such headband models are commonly made of energy-absorbing polymeric foams because of their low density and high energy absorption capacity [2,4].

Previous studies have explored how to optimize headband designs to increase impact absorption [2,4,5]. However, such studies have almost exclusively focused on single-layer headband designs that consist of one layer of impact-absorbing material. Therefore, in this study, a novel two-layer headband model consisting of one inner layer of expanded polystyrene (EPS) and a second outer layer of expanded polypropylene (EPP) was designed and evaluated through finite element analysis. This two-layer headband model was hypothesized to optimize impact absorption by integrating the material properties of both EPS and EPP foam.

II. Materials & Methods

EPP is a polymeric foam that absorbs impact energy by compressing air in its cells, which does not damage its cell walls and thus allows it to recover back to its original shape [4]. Conversely, EPS is a polymeric foam that absorbs impact energy by crushing its cell walls, which prevents it from recovering back to its original shape. However, EPS foam boasts a higher energy absorption capacity than EPP foam [4]. Therefore, layering EPP and EPS foam in one headband may optimize impact absorption: the headband can maintain structural integrity and remain recoverable after impact through EPP foam while increasing its energy absorption capacity through EPS foam. The material properties of EPP and EPS foam are shown below in Table 1. They were obtained from a previous study on energy-absorbing foams [4]. For comparative purposes, the densities of EPP and EPS foam were set equal.

TABLE I. Material Properties

Material	***Density (kg/m^3)***	***Young's Modulus (E) (N/m^2)***	***Poisson's Ratio***
EPP Foam	63	7.25e+6	0.3
EPS Foam	63	1.275e+7	0.3
Human Skull	3312	6.5e+9	0.2

The two-layer EPS-EPP headband was modeled with an inner layer of EPS foam 7mm wide and an outer layer of EPP foam 8mm wide. To comparatively evaluate the EPS-EPP headband, two single-layer headbands were also modeled: one fully EPS-based and one fully EPP-based headband. The EPS-based headband was modeled with a single layer of EPS foam 15mm wide. Likewise, the EPP-based headband was modeled with a single layer of EPP foam 15 mm wide. All three headbands were modeled with a height of 45mm and spanned the length of a human skull model. Note that all three headbands were modeled via Onshape, a CAD platform.

To evaluate the three headbands, realistic finite element simulations of head-to-head impacts were conducted. As shown in Fig. 1, two human skull models were placed in a rear-to-front position. The rear skull was fitted with a headband, whereas the front skull was not fitted with a headband. The rear skull was simulated to move towards the front skull with a velocity of 4 m/s at an angle of elevation of +30 degrees relative to the front skull. This simulation setup represented a realistic head-to-head collision of two players during an aerial duel for the soccer ball, a common situation that can lead to a concussion [2,6].

The human skull model was obtained from an open-source CAD-sharing environment called GrabCAD (skull-7) and was edited with SimScale, an engineering simulation software. Material properties of the skull, displayed above in Table 1, were obtained from a study on a finite element model of the human head [5]. All simulations were carried out through SimScale. As shown in Fig. 1, a mesh with 160k cells and 35k nodes was generated for the simulation. Impact event time was limited to 0.014 seconds because of computational constraints.

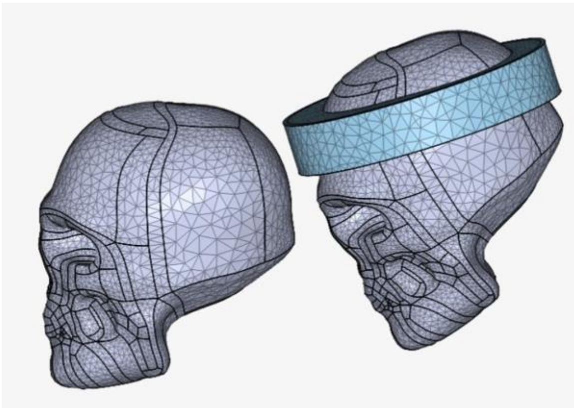

Figure 1. Meshed geometries for head-to-head impact simulation

III. RESULTS & DISCUSSION

The results of the simulations are displayed in Table 2. Peak linear acceleration and peak von Mises stress values were calculated and analyzed for each of the three headbands because they are strong predictors of concussion [7]. Table 2 shows that the peak linear acceleration of the skull fitted with the EPS-EPP headband was 513 (m/s^2), the lowest value out of the three headbands. Likewise, the skull fitted with the EPS-EPP headband also had the lowest peak von Mises stress with a value of 2.35e+04, or 23,500 ($N/m^{2.}$).

TABLE II. SIMULATION RESULTS

Headband Design	***Peak Linear Acceleration (m/s^2)***	***Peak Von Mises Stress (N/m^2)***
EPP	635	2.52e+04
EPS	791	3.78e+04
EPS-EPP	513	2.35e+04

Fig. 2 displays a Time vs. von Mises stress graph that shows how von Mises stress values of the skull changed over the impact time span of 0.014 seconds.

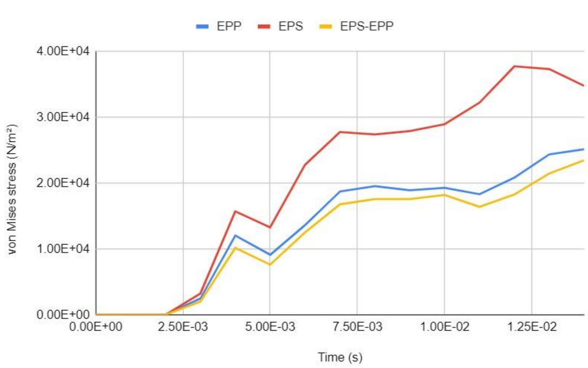

Figure 2. Time vs. von Mises stress

The yellow EPS-EPP curve shows that for the entirety of the impact event, the skull fitted with the EPS-EPP headband had lower von Mises stress values compared to the two single-layer headbands. Overall, the data indicate that the EPS-EPP headband model was superior at absorbing impact energy in a head-to-head collision compared to the two single-layer headbands. This confirms our initial hypothesis because integrating the material properties of both EPS and EPP foam into one headband led to greater impact absorption.

Peak linear acceleration values were utilized to calculate concussion risk based on a concussion threshold curve from Fernandes et al., which is displayed in Table 3 [7]. The skull fitted with the EPS-EPP headband had a peak linear acceleration of 513 (m/s^2), translating to a concussion risk below 25%. Next, the skull fitted with the EPP headband had a peak linear acceleration of 635 (m/s^2), translating to a concussion risk between 25 to 50%. Finally, the skull fitted with the EPS headband had a peak linear acceleration of 791 (m/s^2), translating to a concussion risk greater than 50%. Therefore, the EPS-EPP headband was able to most significantly reduce concussion risk by effectively absorbing impact during the head-to-head collision, once again demonstrating the potential feasibility of a two-layer headband design.

TABLE III. CONCUSSION THRESHOLD VALUES

Peak Head Linear Acceleration (m/s^2)	559	778	965
Probability of Concussion (%)	25	50	75

IV. CONCLUSION

Ultimately, this study demonstrates the feasibility of a two-layer soccer headband design that integrates two polymeric foams − EPP and EPS − to maximize its impact-absorbing ability. With further research, similar two-layer headband designs have the potential to be worn by soccer players in real life, hopefully reducing the incidence of concussions and transforming soccer into a safer game for all.

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