The Efficacy of Impact-absorbing Materials During Collision With a Soccer Ball

Zahari Taha[1,a], Mohd Hasnun Arif Hassan*[1,b], and Mohd Azri Aris[1,c]

[1]Centre for Sports Engineering, Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

[a]zaharitaha@ump.edu.my, [b]hasnun@ump.edu.my, [c]azriaris9@yahoo.com

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Abstract. The uniqueness of soccer is that the players are allowed to use their head to pass the ball to a teammate of even try to score goal. Studies have shown that heading in soccer might be dangerous to the brain and could lead to brain trauma. There are headgears available for soccer players to protect their head, but studies have proven that currently available headgears are ineffective in reducing the impact caused by a soccer ball. The objective of this study is to test the efficacy of six different types of impact-absorbing materials in reducing the linear impact force from a soccer ball. The soccer ball was dropped from the height of 2.3 m onto a force platform to measure the impact force. A high-speed camera is used to record the motion and the impact duration, and then the coefficient of restitution for each impact was determined. Polyurethane (PU) comb-gel was found to be the most effective material in reducing the peak impact force and impulse compared with other materials. The reduction in peak force was associated with longer impact duration between the soccer ball and the PU comb-gel. However, the coefficient of restitution was reduced by 21.7%, implying that using the gel alone will reduce the speed of the ball after heading, thus reducing the performance of a player wearing it. A combination of PU gel and another stiffer material is suggested and the effectiveness of the composite will be the subject of future investigation.

Introduction

Soccer is the most popular sports in the world played by millions of people. There are currently 265 million players worldwide that are actively involved in the game of soccer [1]. The uniqueness of this game is that the players are allowed to use their heads to direct the ball to the teammates or even trying to score goal. Thus, soccer players are susceptible to head injuries and concussions. Studies have shown that more than 70% of concussed soccer players did not realize that they had suffered concussion [2].

Most of the concussions in soccer occur due to head-to-head contact. Other factors include the impact between the head and elbow, knee, ground and also the impact with the ball itself that occurs during purposeful heading [3]. In a single game of soccer, a player can be subjected to six to twelve heading occasions [3-5]. A professional soccer player experiences a median of 800 heading occasions every season excluding the headings that take place during training sessions [3]. There has been a long debate among researchers of whether purposeful heading can lead to brain injury. Several studies have shown some results that support the argument that intentionally heading the ball in soccer can cause mild traumatic brain injury (TBI).

In 1991, thirty-seven former soccer players from Norway were examined through a comprehensive series of psychological tests [6]. The tests have shown that 81% of the former soccer players exhibited mild to severe impairments regarding attention, concentration, memory and judgement. Moreover, ten regular headers showed a higher degree of severe to gross neuropsychological impairment compared to non-headers. They have concluded that the impact of heading the ball shows convincing evidence of brain damage similar to that found in patients who have sustained minor head injuries.

Another study was conducted to determine whether amateur soccer players exhibit the sign of chronic TBI [5]. Thirty-three amateur soccer players were studied alongside 27 amateur swimming and track athletes that served as control group. They have found that amateur soccer players showed lower performance on tests of planning and memory compared to the control group. Furthermore, they have discovered that the number of headings is inversely related to the neuropsychological performance; hence suggest that heading in soccer can lead to chronic TBI.

Apart from the amateurs, a group of 84 professional soccer players were evaluated through neuropsychological tests to determine the relation between the number of headings in a season and the number of soccer-related concussions with the cognitive function [7]. It was found that increasing number of headings has resulted in poorer performance in tests regarding focused attention and memory, whereas the number of soccer-related concussions was proportional to poorer results on sustained attention and visuoperceptual processing evaluation.

A recent study has revealed that repetitive heading occasions experienced by soccer players could lead to degeneration of brain cells [8]. In this study, 32 amateur soccer players were examined using diffusion tensor imaging (DTI), an advanced magnetic resonance (MR) technique. They have measured the movement of water molecules along nerve fibres called axons. This measurement is known as fractional anisotropy (FA), in which in a healthy brain, the FA values are high. They have found that frequent headers had notably lower FA values in five brain regions that are responsible for attention, memory, executive functioning and higher-order visual functions. They have also discovered a threshold level of approximately 1,000 to 1,500 headings per year, in which exceeding this threshold will cause the FA values to decrease significantly.

The concerns of possible brain injury in soccer have resulted in the development of headgears with various designs. A study sponsored by FIFA's sports medicine committee concluded that headgear is beneficial during head-to-head collisions, but it has no effect in head-to-ball impact [9]. McIntosh et al. stated that laboratory studies testing headgear to reduce concussion in soccer are inconclusive. The evidence that the headgear may protect the brain while playing soccer is very weak [10]. Currently available commercial headbands were found to be ineffective in attenuating the impact during simulated soccer heading [11]. Headbands tested exhibited no measurable protection at lower speeds or at lower inflation pressures. Another study has shown that when using a commercial headgear (Full90 Premiere), the resulting HIP value is reduced by less than 5%, which means that the reduction of the injury risk is very small [12].

Those studies have shown that to date, there is no headgear that could minimize the impact force exerted on the brain during a heading occasion. The purpose of this study is to investigate the effectiveness of six impact absorbing materials – NP Gel (Taica Corporation, Japan); Poron XRDMA 12118 (Rogers Corp, USA); D30 recoil pad (MUSTO Ltd, England); polyurethane comb-gel (GELTEC Industry Ltd,

Taiwan); high-grade PVC yoga mat (Trax Active); and kneepad foam (RCL, Malaysia) – in reducing impact from a linear blow by a soccer ball as measured by peak force of impact, time to peak force, and impulse.

Methodology

A string is attached to a size-5 soccer ball through one of its stiches. The string is wrapped around a pulley and the ball is dropped from the height of 2.3 metres onto a tri-axial force platform (Advanced Mechanical Technology, Inc.) as shown in Figure 1. The force platform is connected to a computer through an AMTI Gen 5 signal conditioner. The ball is inflated to the manufacturer's recommended air pressure of 0.7 bars. The air pressure of the ball is regularly checked throughout the experiment. The ball is dropped for five times and the data is recorded using the AMTI Net Force software (version 3.5.1). The materials are placed on the force platform one by one and the procedure is repeated for each material.

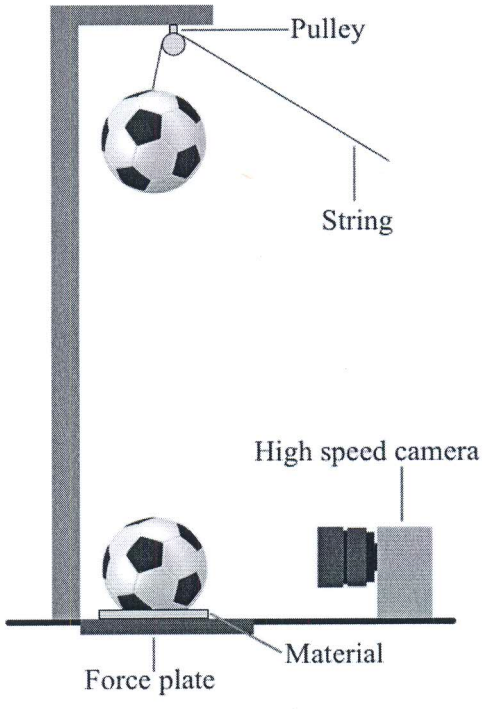

Fig. 1: Experimental setup.

Each trial is 1 second in duration, with data collected at 1000 Hz. The recorded data is read using BioAnalysis software (version 2.3.1, Biosoft), and then imported into Microsoft Excel where the resultant forces are calculated and the peak resultant force for each trial is determined. The average peak resultant force is calculated from the five trials. The impulses are determined from the area under the force curve from the beginning to the end of the impacting force.

A high-speed camera (type SV643C, EPIX, Inc.) is used to capture the high-speed images of the motion of the ball during the experiment. The camera is placed on the ground parallel to the dropping position of the ball. The camera is operated using XCAP software (version 3.7, EPIX, Inc.) and set to record 1000 frames per second with the pixel clock set at 50 MHz. From the images recorded, the velocity of the ball before and after impact can be determined and the coefficient of restitution is calculated.

Results and Discussion

In our study, the ball was dropped from a height of approximately 2.3 m, which was the maximum height possible in the laboratory where the experiment was conducted. Theoretically a ball dropped from this height will generate a velocity of 6.72 m/s. However due to air resistance and the friction between the string and the pulley, the average velocity of the ball before impact measured from the high-speed video was 5.94 m/s. The velocity of the ball generated was lower than the average velocity of the ball during a heading occasion. However, the generated impact was adequate to investigate the efficacy of the materials.

Four main parameters that were determined from the experiment were the peak impact force, impulse, contact time and the coefficient of restitution. From our experiment, all tested materials did reduce the peak impact force compared to control condition ("no material" condition). It was observed that the polyurethane (PU) comb-gel is the most effective in reducing the peak impact force, in which the peak force was reduced by 16.5% as shown in Table 1 and Table 2. The reduction in the peak force is associated with the duration of impact. An increase in the duration of impact will decrease the impact force [11]. The duration of impact between the soccer ball and the PU comb-gel was 11 ms, that is 17.9% longer than the control condition, proving that our results agree with the abovementioned theory.

Table 1: Peak impact force, impulse, contact time and coefficient of restitution.

Condition	Peak force (N)	Average impulse (Ns)	Impact duration (ms)	Coefficient of restitution
No material	1117.76	5.146	9.333	0.824
High-grade PVC	1089.98	4.956	8.800	0.759
D3O	1084.86	5.088	9.000	0.834
PU comb-gel	933.62	4.704	11.000	0.645
NP Gel	1105.07	5.310	8.667	0.860
Poron XRDMA 12118	1098.65	5.107	8.800	0.835
Kneepad foam	1016.84	5.219	10.000	0.832

Table 2: Percentage difference compared with control condition.

Condition	Peak force (%)	Average impulse (%)	Impact duration (%)	Coefficient of restitution (%)
No material	-	-	-	-
High-grade PVC	(−) 2.5	(−) 3.7	(−) 5.7	(−) 7.8
D3O	(−) 2.9	(−) 1.1	(−) 3.6	(+) 1.2
PU comb-gel	(−) 16.5	(−) 8.6	(+) 17.9	(−) 21.7
NP Gel	(−) 1.1	(+) 3.2	(−) 7.1	(+) 4.4
Poron XRDMA 12118	(−) 1.7	(−) 0.8	(−) 5.7	(+) 1.4
Kneepad foam	(−) 9.0	(+) 1.4	(+) 7.1	(+) 1.1

(+) Increase compared with control condition.
(−) Decrease compared with control condition.

The kneepad foam, the second best material in terms of peak impact force reduction, showed a 9% decrease in peak force, and 7.1% increase in the duration of impact. This also proves that longer duration of impact will generate lower peak

force. Other materials showed much smaller decrease in peak impact force compared with the PU comb-gel and kneepad foam and therefore they were regarded as ineffective in terms of peak force reduction.

Impulse represents the momentum transmitted through the material. It is the product of the average value of force over the time during which is acts and is represented by the total area under the impact curve (Figure 2). The PU comb-gel has shown a decrease of 8.6% in terms of impulse compared with the "no material" condition, indicating the lowest transfer of energy through the material to the force platform. The kneepad foam, which was the second best material in terms of reducing the peak impact force however showed a 1.4% increase in impulse, suggesting that it is not very effective in reducing the transfer of energy through it.

A headgear should not interfere with the performance of a soccer player during heading, which means that the use of headgear should not increase or reduce the speed of the ball after being headed by the player. This is why the coefficient of restitution is calculated, as it indicates the resulting speed of the ball after an impact with the material. The PU comb-gel has outperformed other materials in terms of peak force and impulse reduction. However, the major drawback of the PU comb-gel was the coefficient of restitution that was determined from the impact. It was shown that the PU comb-gel has reduced the speed of the ball after impact by 21.7%, which implies that if this gel is used as a headgear in soccer, the ball headed by the player will be approximately 21.7% slower compared with bare head heading. The high-grade PVC also showed a decrease of 7.8% of the coefficient of restitution. However, NP gel increased the coefficient of restitution by 4.4%, and this proves why the NP gel has shown an increase of impulse of 3.2%.

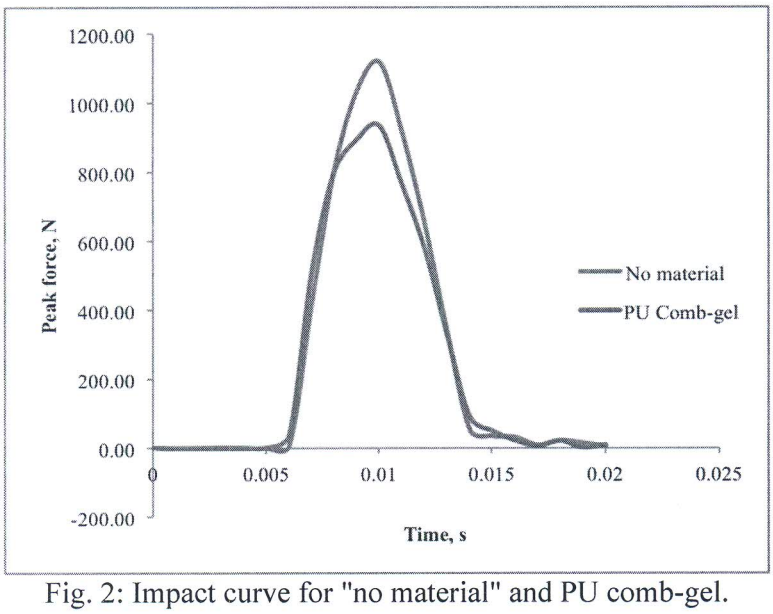

Fig. 2: Impact curve for "no material" and PU comb-gel.

Conclusion

Our findings suggest that impact protection foams are ineffective in reducing the linear impact force from a soccer ball. These foams might be effective during a collision with a rigid object. However, since soccer ball is a deformable object, addition of a soft layer of foam on top of the force platform will not be effective in reducing the peak force. A promising material that can be integrated into the headgear

design is the PU gel. Upon an impact with a soccer ball, the gel will be dispersed to the side. The movement of the gel absorbs the energy from the soccer ball, thus resulting in a reduction of the peak impact force. However, PU gel alone will not make a good headgear since it will decrease the speed of the ball after heading, thus decreasing the chances of scoring goals by heading. Therefore, a composite of PU gel and another stiffer material such as a layer of plastic could solve the problem and will be the subject of future investigation.

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