The effect of pressure and kick speed in soccer on head injury and goalkeeper movement

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Abstract

Soccer balls with different construction types, number of panels, size, pressure, and speed were analyzed. The aim was to understand the effect of pressure on kicked ball speed and the effect of impact speed on head acceleration. A kicked ball speed was obtained from the ball's coefficient of restitution (*COR*), an ideal leg mass and foot speed. The ball *COR* decreased with increasing incident speed and increased with increasing ball pressure. Increasing the ball pressure within allowed limits increased the average kicked ball speed resulting in 26 mm less goalkeeper movement for a 11 m shot on goal. The impact force was more sensitive to speed than pressure. Increasing the ball speed from 13.4 to 22.3 m/s increased the head acceleration from 44 to 81 g. While ball stiffness tended to increase with speed, a bonded size four ball was an exception, which decreased with increasing speed. The results suggest heading high speed ball at low pressure is more dangerous than a high pressure ball at low speed.

1. Introduction

Soccer is a contact sport and heading the ball in soccer is allowed, which sometimes may cause a concussion and mTBI (Mild Traumatic Brain Injury). Studies have shown that as the pressure and speed increase, the impact force increases. Researchers had also found that the *COR* decreases and deformation increases with increasing speed [1]. These studies have not shown how changes in *COR* relate to play conditions, or what mechanisms contributed to the increasing impact force. The following considers the effect of ball pressure and incident speed, representative of play conditions, on the ball speed and impact force.

2. Methods

The following considers soccer balls of size four (205 mm diameter, and 370 g) and five (220 mm diameter, 435 g). A pneumatic cannon was used to project the balls against a rigid flat steel plate. Three load cells (PCB Piezotronics, Model 208C03), each having the maximum load capacity of 2224 N, were used to measure the peak force. The inbound and rebound ball velocity were measured with light gates (Automated Design Corporation, Model ADC-2325-15) spaced 228 mm apart. The soccer ball pressure was measured using a digital pressure gauge (SSI MG Series).

The ball *COR* was found from the ratio of the rebound to inbound speed [1]. A collision efficiency was found from the *COR* and ball weight for each impact. The collision efficiency was used with an ideal leg mass and weight to obtain an ideal kick ball speed as a function of ball pressure and leg speed [2]. The laboratory incident speed, involving a fixed impact surface, was correlated to play speeds with a recoiling body of known mass [3]. To describe an impact with a free recoiling head, for instance, a moment of inertia was 36910 kg-mm^2 with a distance of 200 mm to the last vertebrae C7 for a pivot point was used. From these assumptions, an incident laboratory rigid wall impact speed of 22.3 m/s corresponded to recoiling head incident speed of 27.1 m/s.

3. Results and Discussion

The average *COR* for soccer balls increased with increasing pressure. The allowed pressure range for size five soccer ball is 80 kPa to 100 kPa. To illustrate the significance of ball *COR* on play conditions, consider a 32 m/s penalty kick 11 m from the goal on a ball with 82 kPa pressure. Increasing the ball pressure to 96 kPa increases the ball speed by 1.9 m/s, reducing the time to goal by 8 ms. For a goalkeeper moving at 3.3 m/s [4], this results in 26 mm less goalkeeper movement, which could allow a score and affect the outcome of the match.

The ball impact force increased with an increase in speed and pressure. The impact force is more sensitive to speed than pressure. The maximum linear head acceleration experienced by a player can be found from the peak impact force and head mass. The average head mass for a male adult is 5.34 kg [5]. Increasing the ball pressure from 82 to 96 kPa increased head acceleration from 81 to 85 g for a 22.3 m/s incident ball speed. An increase in speed from 13.4 m/s to 22.3 m/s increased the head acceleration from 44 to 81 g for a ball at 82 kPa. Heading a soccer ball induces a linear acceleration of 15-20 g for a ball travelling at 9-12 m/s [6]. A head acceleration of 82 g has a 50% chance of mTBI while 130 g can produce a subdural hematoma [7]. A player heading a high-speed ball with low pressure, therefore, may have a greater chance of brain injury than a high-pressure ball at low speed.

Ball stiffness was not constant, but increased with speed. The increase in dynamic stiffness with speed is consistent with Hertzian contact, where higher speeds produce increased contact area and consequently higher ball stiffness. The bonded size four ball showed a decrease in dynamic stiffness with increasing speed, this response was unique to this ball model. The average head mass of 12 year youth is 3.57 kg [5]. The linear head acceleration from a stitched size four ball at 13.4 to 22.3 m/s increased from 35 to 68 g, respectively, while head acceleration from a bonded size four ball increased from 42 to 62 g. While the size four bonded model was made from more panels than any other ball considered in this work, the authors were not able to identify a mechanism for its unique stiffness response.

4. Summary

This work considered the effect of pressure and impact speed on the response of nine different soccer ball models. A methodology was presented to show how laboratory tests against a rigid wall correlated to play conditions. The ball *COR* was shown to increase with pressure and decrease with increasing speed. The linear head acceleration was sensitive to speed, and head acceleration increased as speed and *COR* of the ball increased. Consistent with Hertzian contact, the ball dynamic stiffness tended to increase with the impact speed. A size four ball was a notable exception, exhibiting a reduced sensitivity of impact force to speed and a decreasing ball stiffness with increasing speed.

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