BRAIN ACCELERATION DURING BALL-TO-HEAD IMPACT IN SOCCER

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ABSTRACT

There has been a long debate whether purposeful heading could cause harm to the brain. Studies have shown that repetitive heading occasion could lead to degeneration of brain cells, which is similarly found in patients with mild traumatic brain injury. A two-degree of freedom linear mathematical model was developed to study the impact of soccer ball to the brain during ball-to-head impact in soccer. From the model, the acceleration of the brain upon impact can be obtained. The model is a mass-spring-damper system, in which the skull is modelled as a mass and the neck is modelled as a spring-damper system. The brain is a mass with suspension characteristics that are also defined by a spring and a damper. The model was validated by experiment, in which a ball was dropped from different heights onto an instrumented dummy skull. The validation shows that the results obtained from the model are in a good agreement with the brain acceleration measured from the experiment. This findings show that a simple linear mathematical model can be useful in giving a preliminary insight on what human brain endures during a ball-to-head impact.

Keywords: Head impact; Soccer; Mathematical model; Linear impact.

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 (FIFA.com). 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 (Delaney et al., 2002).

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 (Levy et al., 2011). In a single game of soccer, a player can be subjected to six to twelve heading occasions (Levy et al., 2011; Spiotta et al., 2012; Matser et al., 1999). A professional soccer player experiences a median of 800 heading occasions every season excluding the headings that take place during training sessions (Levy et al., 2011). 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).

Tysvaer and Lochen have examined 37 former soccer players from Norway through a comprehensive series of psychological tests (Tysvaer and Lochen, 1991). 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 to the head 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 (Matser et al., 1999). 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.

Matser et al. have also examined a group of 84 professional soccer players 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 (Matser et al., 2001). 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 (Lipton, 2011). 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.

Those studies have shown that there is a need to explore what actually happens to the brain during heading occasion. The acceleration of the brain during ball-to-head impact is the cause of concussion that can lead to traumatic brain injury. Measuring the acceleration of a human brain during an impact is almost impossible. Previous studies have only measured the head acceleration during heading, but none has attempted to specifically measure the brain acceleration. This study proposes a linear mathematical model that measures the acceleration of the brain during an impact with a ball. From the simulation, not only brain acceleration can be measured, but also the duration of the brain vibration.

MATHEMATICAL MODEL

A two-degree-of-freedom linear mathematical model was developed as shown in Figure 1. It is assumed that a ball that travels with a defined velocity impacts the skull that is represented by a mass m_1. It is attached to a spring (stiffness, k_1) and a dashpot (damping coefficient, c_1) that represent the neck. Another mass m_2, which symbolizes

the brain, is attached to the skull by a spring-damper system (stiffness, k_2 and damping coefficient, c_2) that represents the suspension characteristics of the brain.
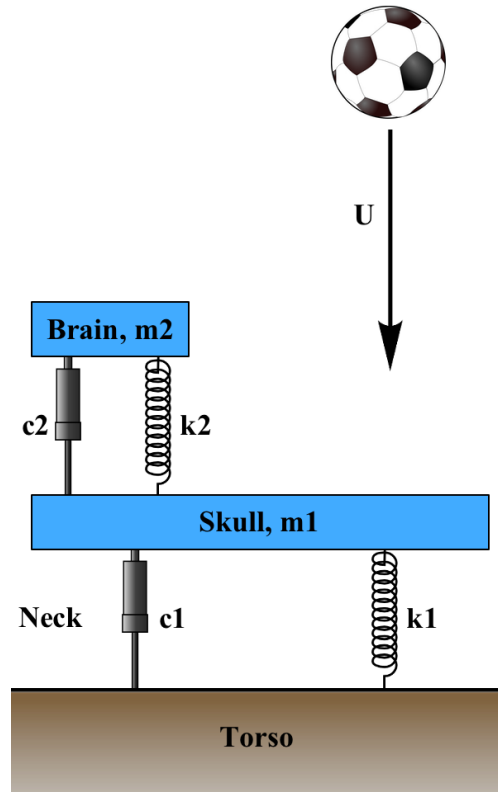

Figure 1. Linear mathematical model of ball-to-head impact.

The mass of the skull was taken as $m_1 = 3.5$ kg, whereas the mass of the brain was taken as $m_2 = 1.3$ kg. The stiffness and damping coefficient of the neck were taken as 1800 kN/m and 450 Ns/m respectively (Dirisala et al., 2012), whereas for the brain, the stiffness were taken as 156 kN/m and the damping coefficient was taken as 340 Ns/m (Baghaei et al., 2009). The acceleration of the skull and the brain are given by Eq. (1) and (2):

$$m_1\ddot{x}_1 = u + m_1 g - k_1 x_1 - c_1 \dot{x}_1 + k_2\left(x_2 - x_1\right) + c_2\left(\dot{x}_2 - \dot{x}_1\right) \tag{1}$$
$$m_2\ddot{x}_2 = m_2 g - k_2\left(x_2 - x_1\right) - c_2\left(\dot{x}_2 - \dot{x}_1\right) \tag{2}$$

Eq. (1) and (2) are second-order differential equations which were numerically solved using Euler method with step size of 0.0001.

EXPERIMENTAL VALIDATION

A dropped-ball experiment was conducted to validate the results obtained from the mathematical model. A ball was dropped from different heights (0.5, 1.0, 1.5 and 2.0 m) onto an instrumented dummy skull, thus creating different ball velocities. The dummy skull was filled with gel that represents the brain, and an accelerometer was placed inside the gel to measure the acceleration of the gel upon impact. The acceleration of the

gel represents the brain acceleration during ball impact. Figure 2(a) illustrates the experimental setup, and Figure 2(b) shows the instrumented dummy skull used.

(a)   (b)
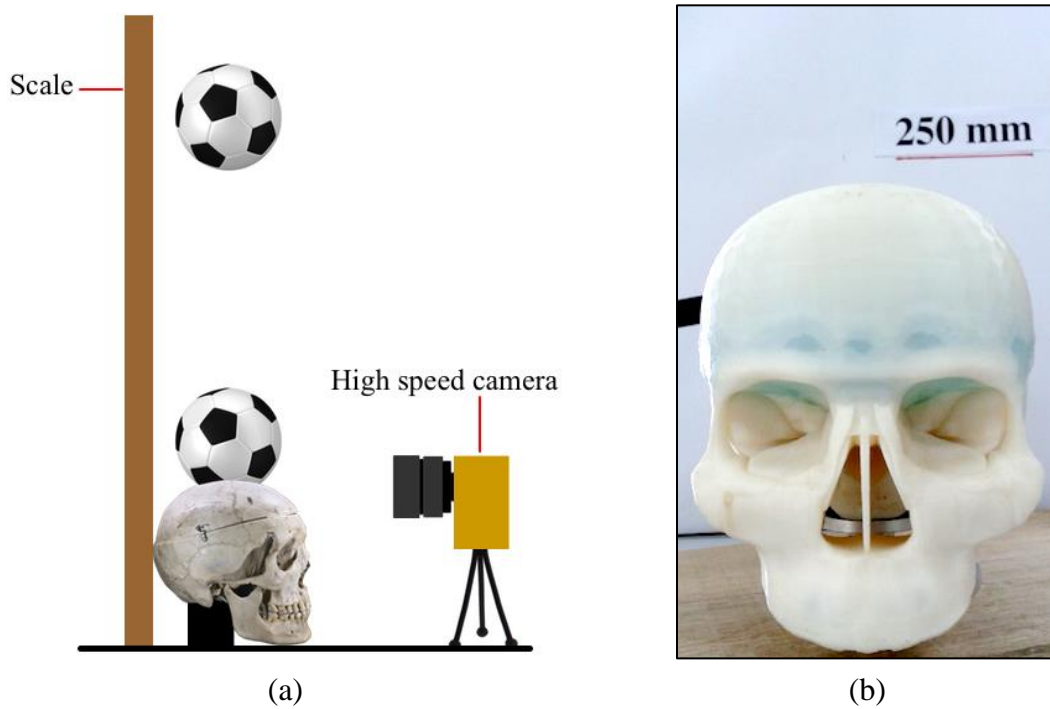
Figure 2. (a) Illustration of the experimental setup; (b) Instrumented dummy skull.

For each height, the experiment was repeated three times and the average peak brain accelerations were recorded. The tri-axial accelerometer was connected to a data acquisition device and the acceleration was recorded using commercial data acquisition software. The data was then imported into spread sheet software for further analysis.
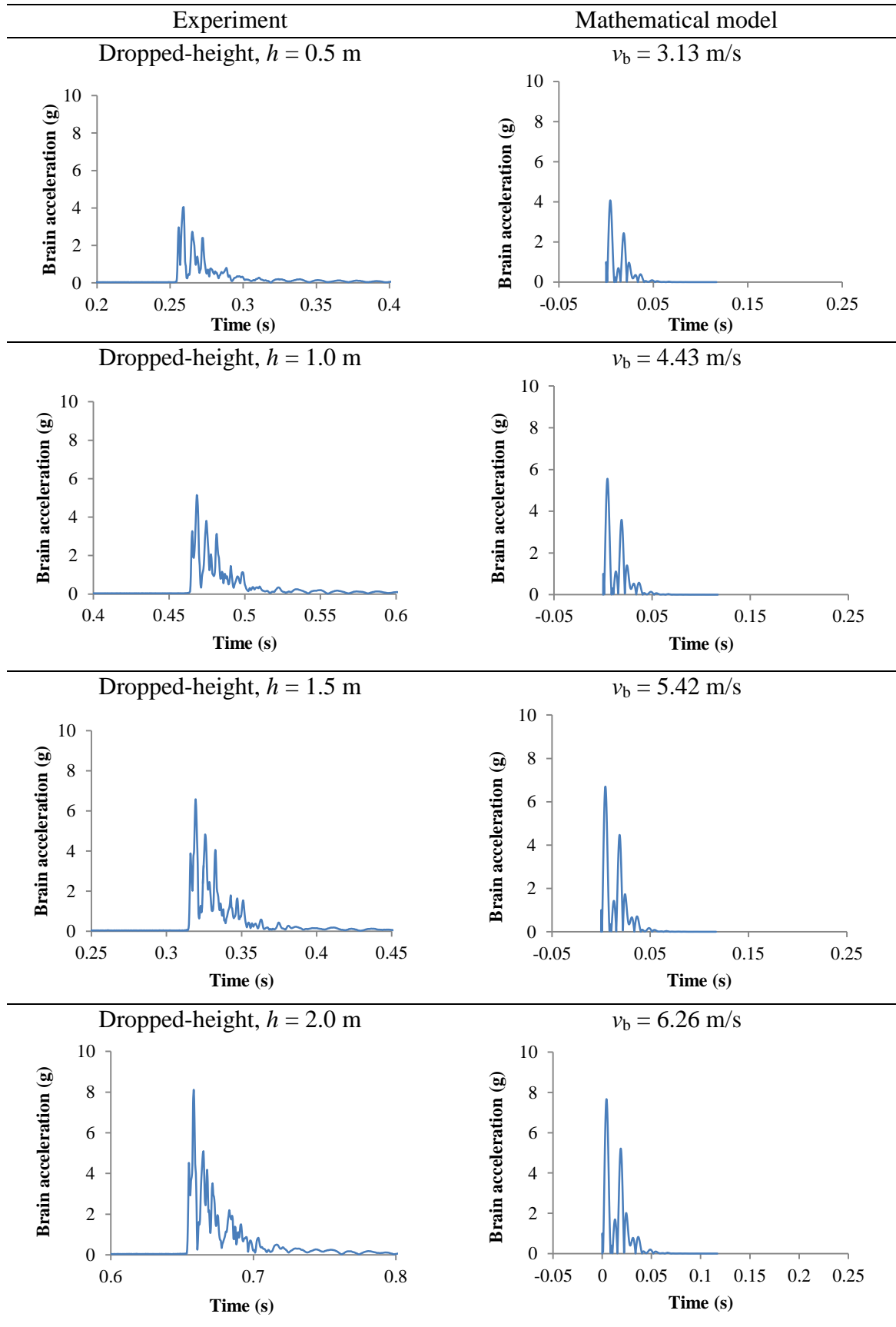
RESULTS AND DISCUSSION

Table 1 shows the comparison between peak brain acceleration obtained from the experiment and the mathematical model. Table 2 shows the profile of the brain acceleration obtained from both mathematical model and the experiment. The profiles were obtained by calculating the resultant of the accelerations from each axis.

Table 1. Peak brain accelerations.

Dropped-height (m) / Ball velocity (m/s)	Peak brain acceleration (g)		Difference
	Experiment	*Model*	
0.5 / 3.13	3.883	4.074	4.9%
1.0 / 4.43	5.316	5.557	4.5%
1.5 / 5.42	6.250	6.700	7.2%
2.0 / 6.26	8.175	7.669	6.2%

Table 2. Comparison of brain acceleration profile.

Experiment	Mathematical model
Dropped-height, $h = 0.5$ m	$v_b = 3.13$ m/s

Dropped-height, $h = 1.0$ m	$v_b = 4.43$ m/s

Dropped-height, $h = 1.5$ m	$v_b = 5.42$ m/s

Dropped-height, $h = 2.0$ m	$v_b = 6.26$ m/s

From Table 1, it is shown that peak brain accelerations obtained from the mathematical model are in a good agreement with the experimental data. Differences of less than 10% suggest that the values are acceptable. Furthermore, the acceleration profiles obtained from the model are comparable to the profiles obtained from experiment.

CONCLUSION

A two-degree-of-freedom linear mathematical model was proposed to estimate the linear acceleration endured by the brain during ball-to-head impact in soccer. The model was validated through experiment using dummy skull, and the data obtained from both experiment and model was in a good agreement. It is shown that a simple mathematical model is useful in giving an estimation of the acceleration endured by the brain during a ball-to-head impact in soccer. Using mathematical model is beneficial since it offers the flexibility in varying the parameters involved in the impact.

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