INVESTIGATION OF THE HEAD IMPACT POWER OF A *SEPAK TAKRAW* BALL ON *SEPAK TAKRAW* PLAYERS

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Abstract

Sepak takraw is a traditional sport in Asia in which the players use various parts of their bodies to hit the ball, with the exception of their hands. Unlike other sports such as soccer, boxing, and rugby, it is observed that none of the studies in the literature have examined the injuries resulting from the impact of the *sepak takraw* ball on the players' heads during a game. This study was initiated following the incidents of the 24th SEA Games in Korat, Thailand, in year 2007, whereby a number of players from the Malaysian Sepak Takraw Association (PSM) had to withdraw themselves from the championship. These players suffered from headaches which were believed to be caused by the impact of the *sepak takraw* ball, considering the fact that heading is one of the basic movements used to hit the ball. Moreover, it is expected that the *sepak takraw* ball travels at high velocities during the game. Hence, the objective of this study is to investigate the impact of the *sepak takraw* ball and its corresponding level of head injury among *sepak takraw* players in Malaysia by means of numerical simulations and experiments. In order to achieve this objective, a model of the scalp, skull, cerebrospinal fluid and brain is first developed and simulations are then carried out using finite element analysis (FEA) software. The results show that the maximum speed of the *sepak takraw* ball before heading is 13.581 m/s while the maximum impact force on the head obtained from the simulations is 688.11 N. The maximum displacement and maximum linear acceleration of the brain's centre of gravity is found to be 0.0080 m and 1674.5 m/s^2, respectively, while the head impact power (HIP) is determined to be 11.366 kW. According to Newman et al. (2000), the probability of concussion is 39% and based on the results obtained in this study, it can be concluded that the players may suffer from mild traumatic brain injuries (MTBI) due to the high impact of the *sepak takraw* ball during heading. Hence, it is recommended that the players wear protective headbands to reduce the impact during heading and prevent the occurrence of MTBI in the long term.

Keywords: Sepak takraw, head impact power, finite element analysis

Introduction

Sepak takraw, otherwise known as 'kick volleyball' is a popular sport in South-East Asia, in which the players hit a *sepak takraw* ball in the air using their feet, knees, chests or heads. A photograph of a typical *sepak takraw* game is shown in Figure 1.

Figure 1: Photograph of a *sepak takraw* game

Taha et al. (2008) conducted one of the preliminary studies regarding head injuries in *sepak takraw* games in order to develop a technique to measure the head impact power (HIP) of *sepak takraw* balls. They determined the HIP of two balls with the same brand (i.e. Marathon) – one without rubber and the other with impregnated rubber – and the values were compared with the findings of Newman et al. (2000). In addition, they determined the probability of concussion at different HIP values and the results showed that the probability of concussion is 5, 50 and 95% for a HIP value of 4.70, 12.79 and 20.88 kW, respectively. Taha et al. (2008) discovered that when the balls were dropped from a height of 3.5 m, the HIP of the first ball is 4.425 kW whereas the HIP for the second ball is nearly twice the value for the first ball (7.863 kW). They also found that the probability of concussion for the first ball is less than 5%, whereas the probability of concussion for the second ball was 20% – a fourfold increase relative to the first ball. Furthermore, it has been shown that the velocity of a *sepak takraw* ball can reach up to 160 km/hr, which increases the probability of concussion significantly to more than 50%.

In a follow-up study, Taha et al. (2010) determined the HIP of *sepak takraw* ball on players using photogrammetric technique. Photographs of the *sepak takraw* ball when it impacts the players' heads were captured during the Sepak Takraw World Cup Championship in Malaysia held on May 2009. The results showed that the maximum speed of the ball is 17.83 m/s while the maximum HIP is 77.86 kW. Based on the results, they concluded that HIP is a potential cause for moderate neurological injuries and recommended that the players should use headbands during the game.

Even though the majority of sports-related head injuries are focused on minor or mild concussions, this does not mean that the recovery period should be taken lightly. Itabashi (2007) has shown that approximately half of the traumatic deaths are due to head injuries and the death rate attributed to traumatic brain injuries (TBI) is 2%. The majority of those who survive ended up with disabilities, whereas 3% experienced weakness. The probability of a good recovery is roughly 30%, but unfortunately, this is frequently overlooked in the professional sports arena since players are expected to return to the game as soon as possible. According to Schmitt et al. (2007), recurrence of prolonged concussions may cause damage to the brain tissues. Thus, as a precautionary measure, it is best that a player only returns to play after he or she has completely recovered from previous mild concussions. In light of this discussion, the objective of this study is to investigate the impact of the *sepak takraw* ball and its corresponding level of head injury among *sepak takraw* players in Malaysia by means of numerical simulations and experiments.

Methodology

Overview

The data were recorded during the KFC-Utusan Sepak Takraw 2011 Championship held in Kuala Lumpur. The velocity of the *sepak takraw* ball before and after headings (specifically at the forehead) was measured from the recordings, and the data were subsequently used in the simulations of the heading model. The contact time was also measured. Finally, the data obtained from simulations and measurements were compared.

Numerical simulation

A model of the scalp, skull, cerebrospinal fluid and brain was first developed using CATIA computer aided design (CAD) software, as shown in Figure 2.

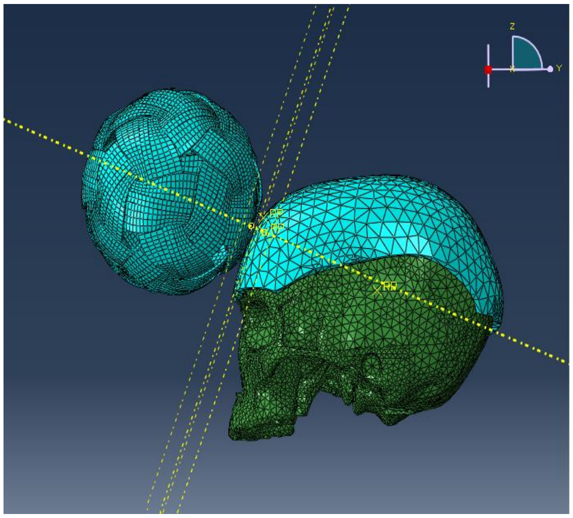


Figure 2: Heading model developed using CATIA software

It is observed that linear elastic (Huang et al., 2000; Morrison III et al., 2003) and linear viscoelastic (Takhounts et al., 2003; Willinger and Baumgartner, 2003; Zhang et al., 2001) properties are typically used for brain simulations. A variety of material properties have been tested in previous studies with varying degrees of success. The material properties of the brain tissues were selected based on the work of Willinger and Baumgartner (2003) and Arbogast and Margulies (1999), and the values are presented in Table 1.

Table 1: Material properties assigned for the brain tissues (Willinger and Baumgartner, 2003; Arbogast and Margulies, 1999)

Parameter	Value
Young's modulus (kPa)	675
Density (kg/m^3)	1040
Poisson's ratio	0.49
Shear modulus (kPa)	226.51
Short-term G_0 (kPa)	49
Long-term G_∞ (kPa)	16.2
Bulk modulus (kPa)	2190000
Decay constant β (s^{-1})	145
Prony series	
g	0.8952310
k	0
τ	0.0103

The material properties assigned for the scalp, skull, cerebrospinal fluid and *sepak takraw* ball are summarized in Table 2.

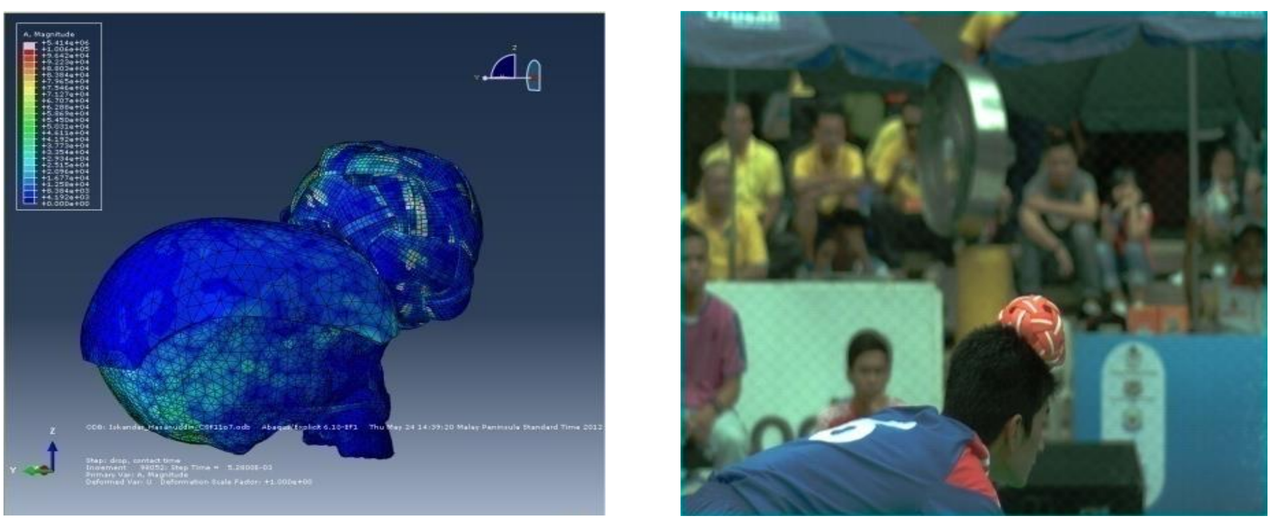
Table 2: Material properties assigned for the scalp, skull, cerebrospinal fluid and *sepak takraw* ball

Part model	Young's modulus (kPa)	Density (kg/m^3)	Poisson's ratio
Scalp	16700	1130	0.42
Skull	15000000	2000	0.22
Cerebrospinal fluid	12	1040	0.49
Sepak takraw ball	1001500	1056.171	0

Note: The material properties for the *sepak takraw* ball were taken from the work of Ahmad (2012).

The traditional *sepak takraw* ball is made of bamboo or rattan which is weaved by hand to form a sphere-shaped ball, which varies in weight and weaving complexity. In 1982, Marathon Intertrade Co. Ltd. modernized the sport by introducing woven synthetic balls, whereby the basic material is polypropylene, which is a type of plastic. The characteristics of *sepak takraw* balls have become standardized since then. According to the guidelines of the International Sepak Takraw Federation (2004), plastic *sepak takraw* balls should have a covering of 12 holes and 270 intersections with 18 strips (Ahmad et al., 2012). The circumference of the ball must be within a range of 42–44 cm and 43–45 cm for men and women, respectively. The weight of the ball must be within a range of 170–180 g and 150–160 g for men and women, respectively.

Once the material properties had been assigned, the mesh was generated for each part. Following this, the interaction of the parts in the heading model, along with the boundary conditions, loading and step were defined for explicit, dynamic analysis of the *sepak takraw* ball. The velocity of the *sepak takraw* ball was keyed into the interface of the Abaqus CAE software, and the FEA simulations were then carried out. A screenshot of the heading model obtained from the simulations is shown in Figure 3a, which is comparable to the photograph taken during the KFC-Utusan Sepak Takraw 2011 Championship shown in Figure 3b. A view cut of the heading model is shown in Figure 4. The methodology used for the FEA simulations is summarized in Figure 5.



(a) (b)

Figure 3: (a) Screenshot of the heading model from FEA simulations and (b) photograph of a player heading the *sepak takraw* ball during the KFC-Utusan Sepak Takraw 2011 Championship

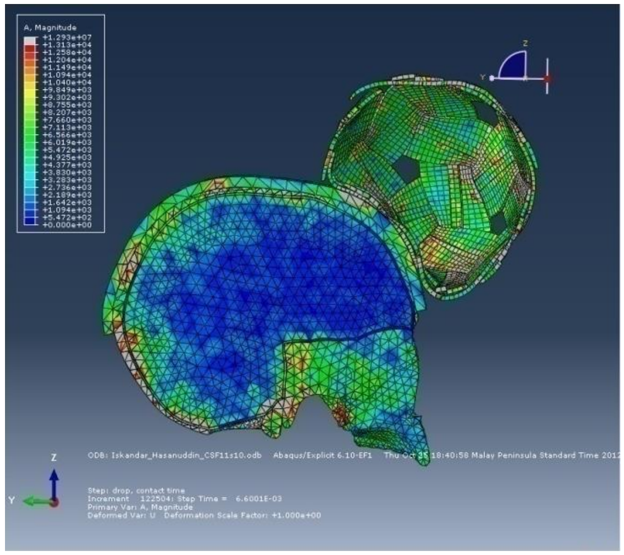


Figure 4: Screenshot of the heading model from FEA simulations (view cut)

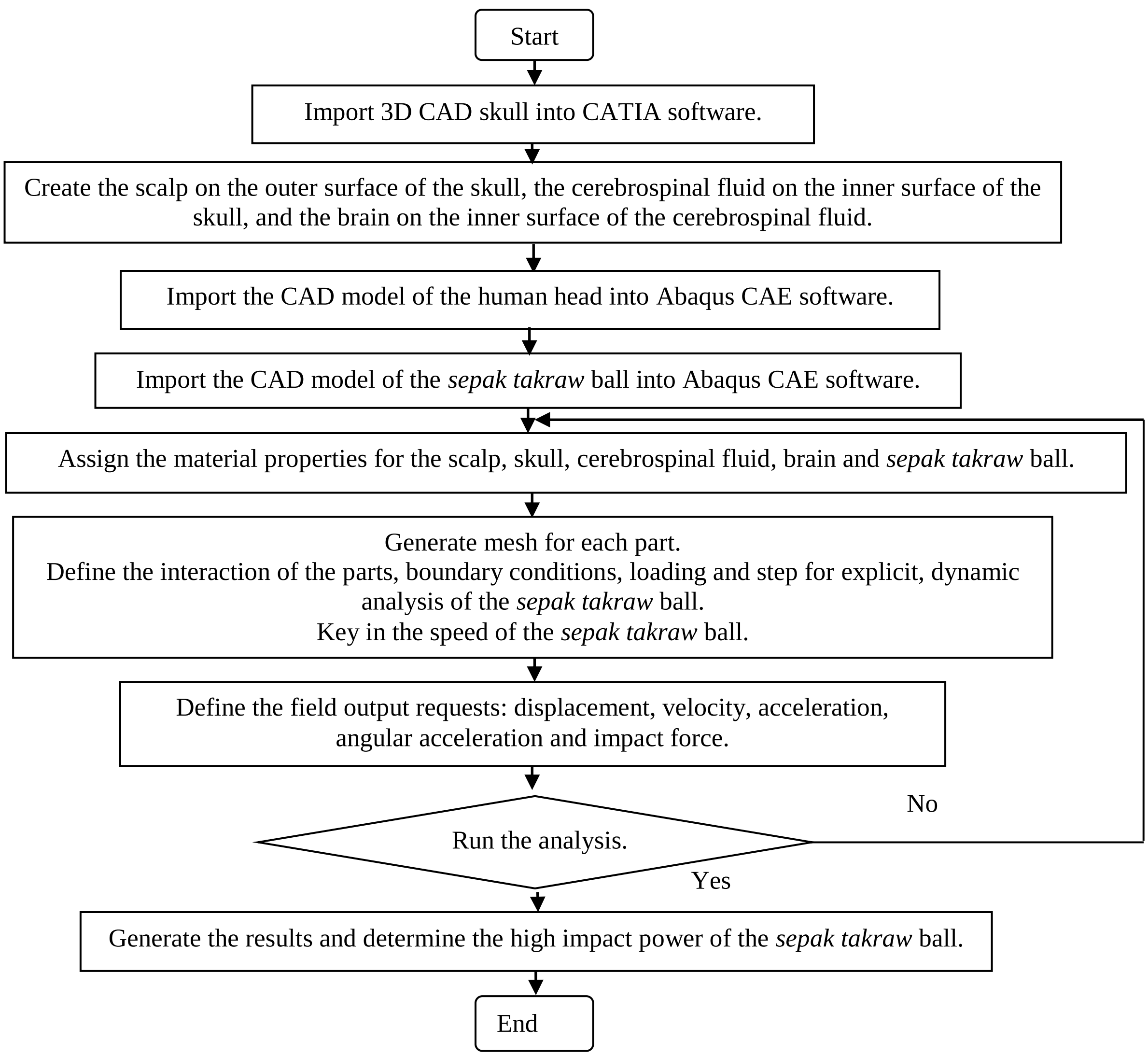


Figure 5: Flow chart of the methodology used in this study to simulate the heading model using finite element analysis

Head impact power

The following equation was used to calculate the head impact power of the sepak takraw ball (Newman et al., 2000):

$$HIP = C_1 a_x \int a_x dt + C_2 a_y \int a_y dt + C_3 a_z \int a_z dt + C_4 \alpha_x \int \alpha_x dt + C_5 \alpha_y \int \alpha_y dt + C_6 \alpha_z \int \alpha_z dt \quad (1)$$

where C_i represents the coefficients for the mass and moments of inertia of the human head (50th percentile). In this study, $C_1 = C_2 = C_3 =$ 4.5 kg, C_4 = 0.016 Nm^{-2}, C_5 = 0.024 Nm^{-2} and C_6 = 0.022 Nm^{-2}. a_x, a_y and a_z (ms^{-2}) represent the components of linear acceleration along the three axes of the inertia reference space attached to the head model. α_x, α_y and α_z (rads^{-2}) represent the components of angular acceleration about the three axes of the inertia reference space attached to the head model.

Results and discussion

Contact time and total impact force of the sepak takraw ball

The results obtained in this study are presented and discussed in this section. Comparison is made between the results obtained from FEA simulations and images captured during the KFC-Utusan Sepak Takraw 2011 Championship. Figure 6 shows the contact time between the *sepak takraw* ball and the forehead of the player and the total impact force exerted by the ball on the player's head during heading. It is found that the contact time is 0.01023 s while the maximum total impact force is 688.11 N. It shall be noted that these values are obtained when the velocity of the *sepak takraw* ball before impact is 13.581 m/s.

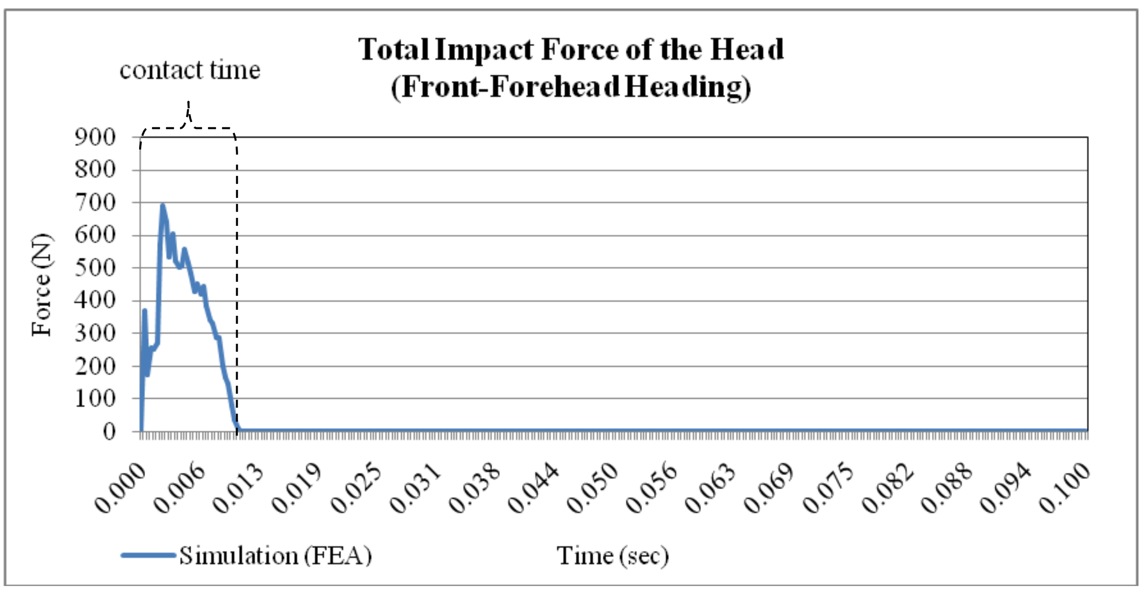


Figure 6: Contact time and the total impact force exerted by the *sepak takraw* ball on the head of the player during heading

Velocity of the sepak takraw ball

Figure 7 shows the variation in the velocity at the centre of *sepak takraw* ball during heading. It can be seen that the velocity of the ball first decreases until it reaches a minimum point, followed by an increase until it reaches a point where the velocity becomes stable. The simulation result shows good agreement with the velocity measured from experiments, with a percentage similarity of 95.01%.

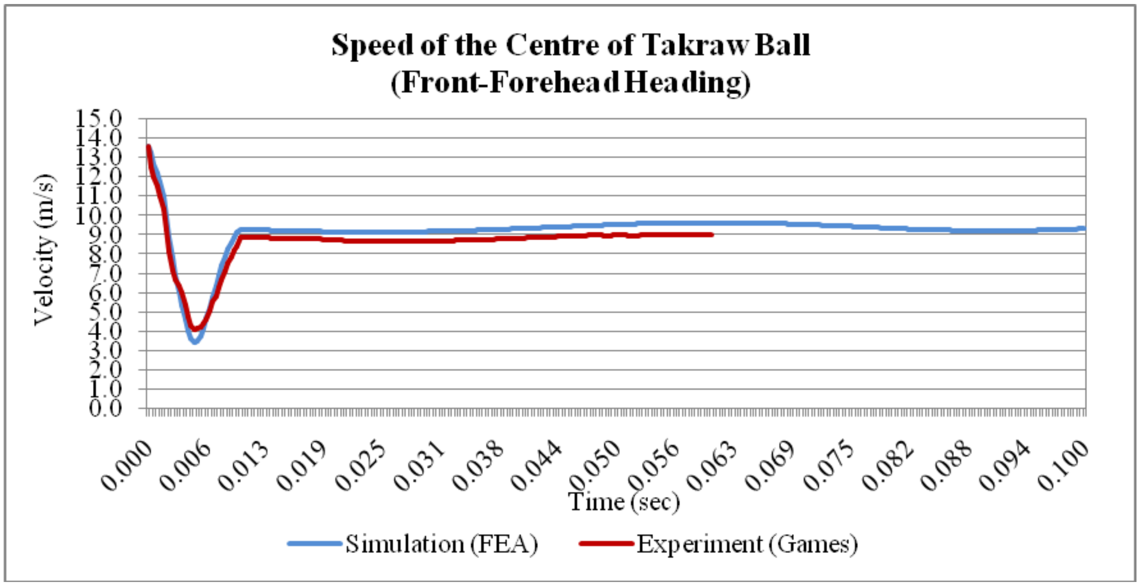


Figure 7: Velocity at the centre of the *sepak takraw* ball during heading

Displacement of the brain's centre of gravity

Figure 8 shows the displacement of the brain's centre of gravity during heading from FEA simulations. The maximum and minimum displacement of the brain's centre of gravity in the y-axis is 0.459×10^{-3} m and -0.228×10^{-3} m, respectively. However, the maximum displacement of the brain's centre of gravity in the x, y and z-axis after impact is 0.0008×10^{-3} m, 0.0824×10^{-3} m and 0.0247×10^{-3} m, respectively.

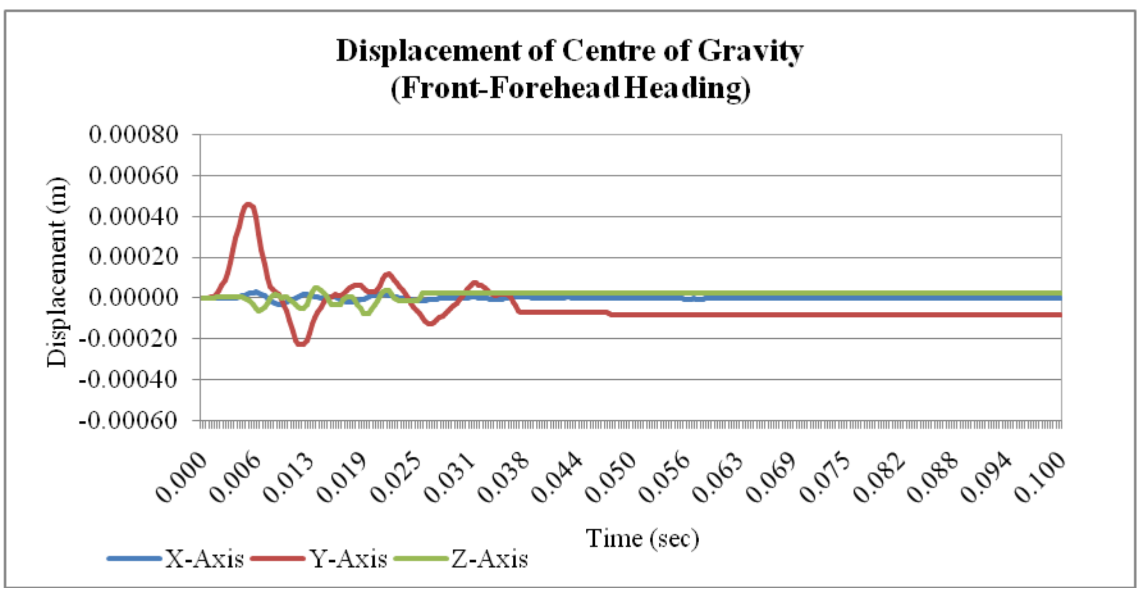


Figure 8: Displacement of the brain's centre of gravity during heading

Velocity of the brain's centre of gravity

Figure 9 shows the velocity of the brain's centre of gravity during heading. The maximum and minimum velocity of the brain's centre of gravity in the y-axis is found to be 0.168 m/s and -0.236 m/s, respectively.

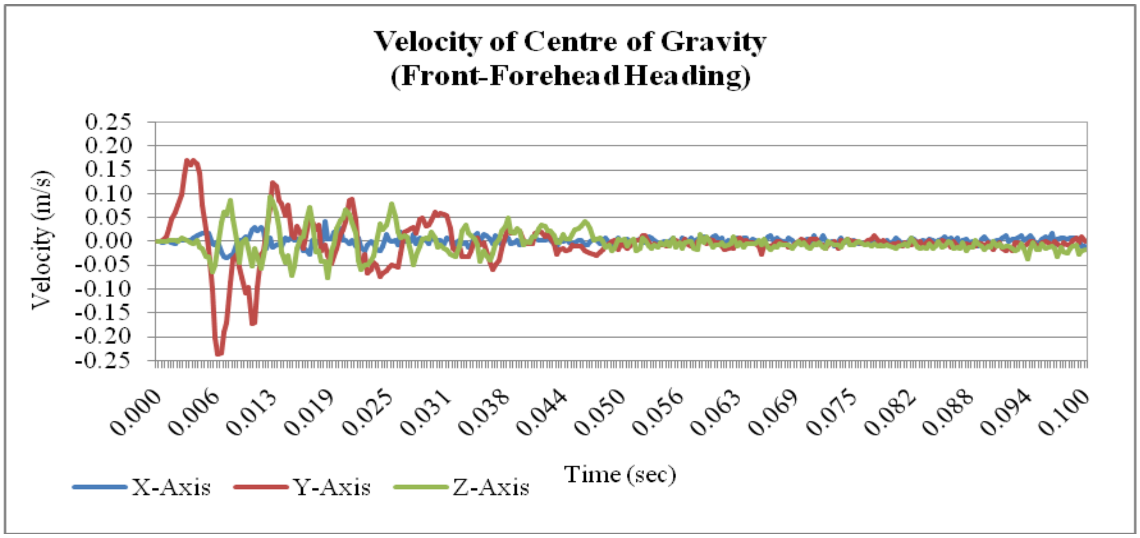


Figure 9: Velocity of the brain's centre of gravity during heading

Linear acceleration of the brain's centre of gravity

Figure 10 shows the linear acceleration of the brain's centre of gravity during heading. The maximum and minimum acceleration of the brain's centre of gravity in the x-axis is determined to be 1667.8 m/s^2 and -1358.6 m/s^2, respectively. The maximum acceleration is highest in the y-axis, with a value of 1674.5 m/s^2 whereas the minimum acceleration is -1462.1 m/s^2. In contrast, the acceleration of the brain's centre of gravity is lowest in the z-axis, whereby the maximum and minimum value is 1591.5 m/s^2 and -1543.3 m/s^2, respectively. It is evident from Figure 10 that the acceleration of the brain's centre of gravity varies with time during heading in all three axes.

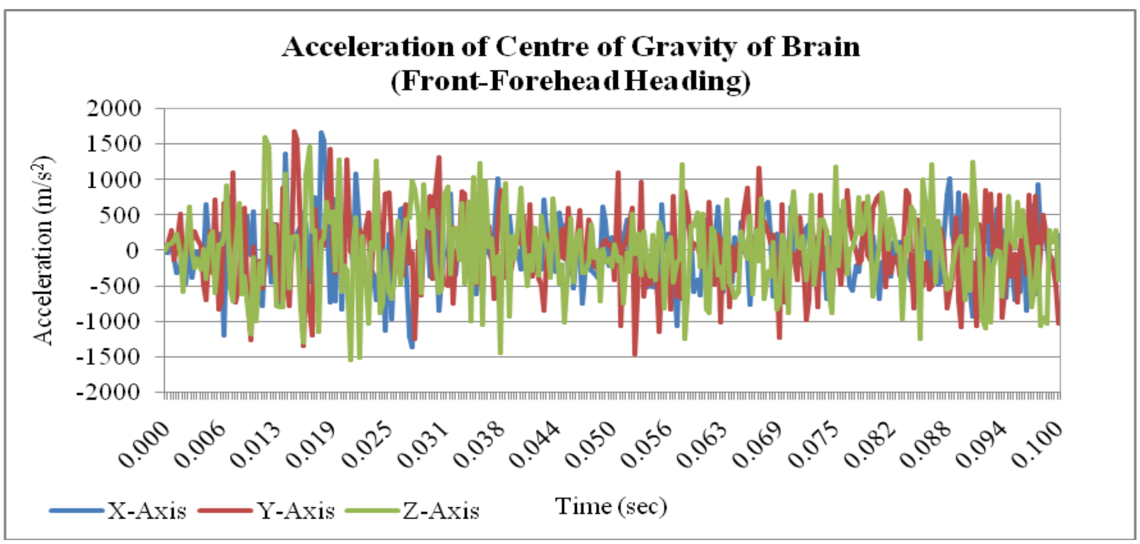


Figure 10: Linear acceleration of the brain's centre of gravity during heading

Head impact power

The values for the various parameters used to determine the HIP using Equation (1) are listed as follows:

C_1 = 4.5 kg	C_2= 4.5 kg	C_3 = 4.5 kg
C_4 = 0.016 N/m^2	C_5 = 0.024 N/m^2	C_6 = 0.022 N/m^2
a_{x1}= 1667.8 m/s^2	a_{y1} = 1674.5 m/s^2	a_{z1} = 1591.5 m/s^2
a_{x2} =1551.1 m/s^2	a_{y2} = 1572.7 m/s^2	a_{z2} = 1472.7 m/s^2
t_1 = 0 s	t_2 = 0.00033 s	
α_{x1} = 1.536 rad/s^2	α_{y1} = 11.239 rad/s^2	α_{z1} = 15.266 rad/s^2
α_{x2} = 1.296 rad/s^2	α_{y2} = 9.207 rad/s^2	α_{z2} = 14.909 rad/s^2

The HIP is obtained to be 11.366 kW, given that the velocity of the *sepak takraw* ball is 13.581 m/s. The probability of concussion based on HIP values during heading is shown in Figure 11. According to Newman et al. (2000), the probability of concussion based on a HIP value of 10 kW is approximately 39%, as indicated by the red solid line in Figure 11.

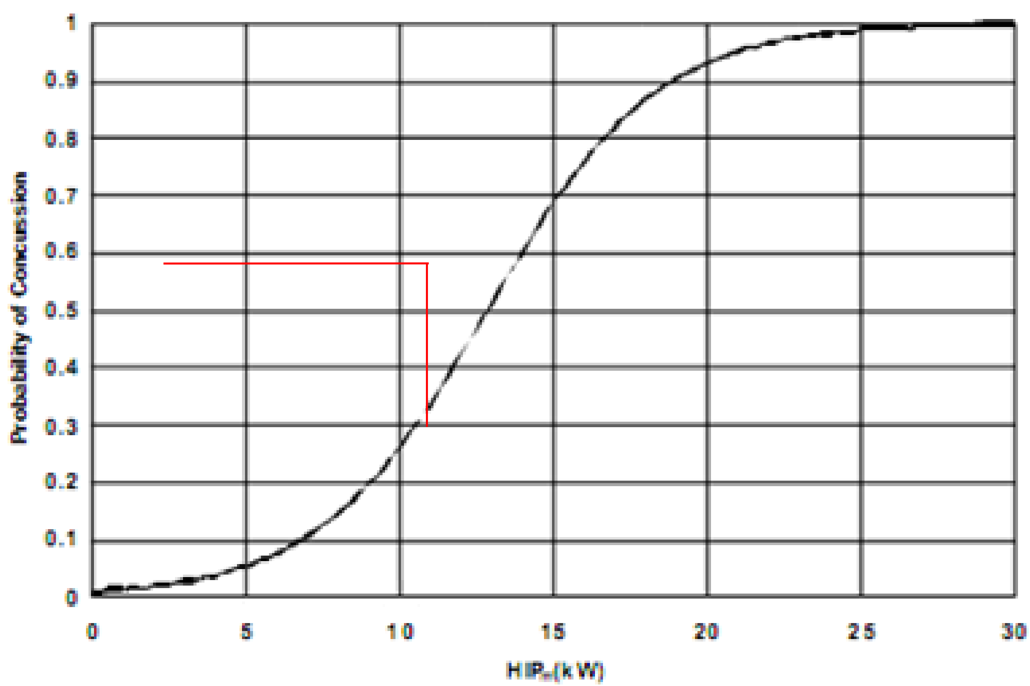


Figure 11: Probability of concussion based on HIP during heading (Newman et al., 2000)

Figure 12 shows the HIP of the *sepak takraw* ball at various velocities (5.000, 10.000, 13.581 and 15.000 m/s) before impact. It can be seen that the trend is fairly linear, in which the HIP increases with an increase in velocity of the *sepak takraw* ball. The maximum HIP is found to be 13.639 kW when the velocity of the ball is 15 m/s, which corresponds to a probability of concussion of 51%.

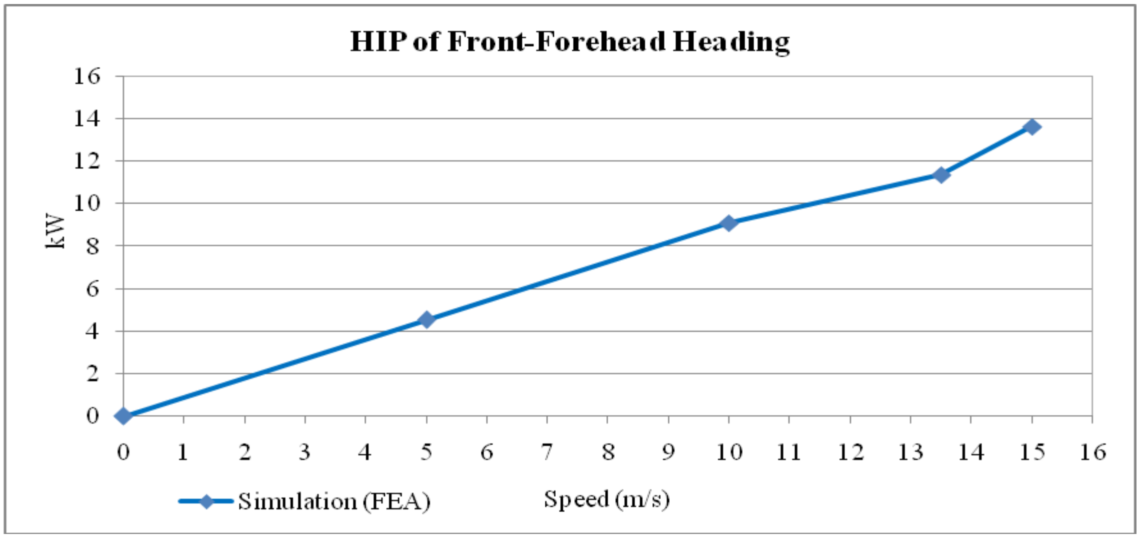


Figure 12: HIP of *sepak takraw* ball at various velocities

Maximum average acceleration of the brain

The maximum average acceleration of the brain obtained in this study is superimposed with the Wayne State Concussion Tolerance Curve (WSTC) by Gurdjian et al. (1955) and Gadd (1966), as shown in Figure 13. It is found that the maximum average acceleration of the brain during heading is 199.187 m/s^2 (20.31 g) at a contact time of 0.011 s, as indicated by the red line. It can be seen that the maximum average acceleration of the brain is well below the threshold of fatal injury.

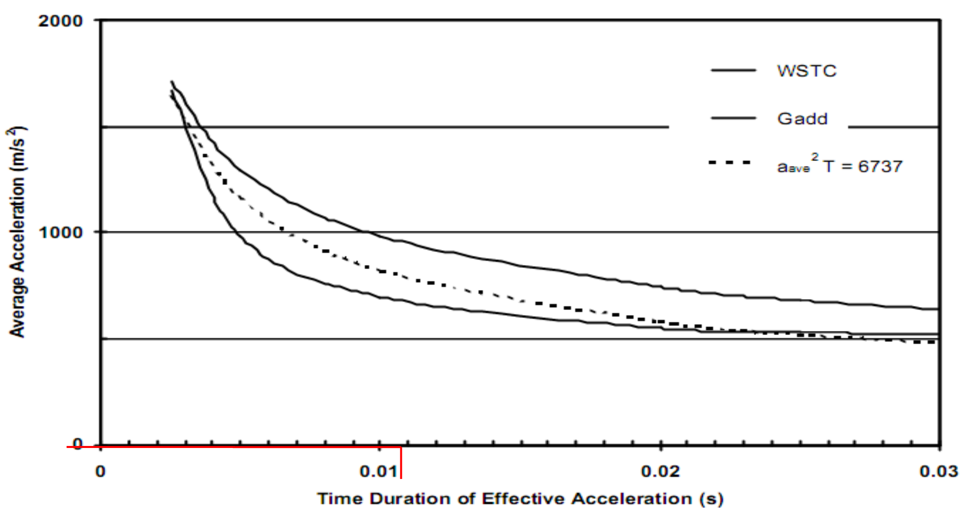


Figure 13: Maximum average acceleration of the brain superimposed with the Wayne State Tolerance Curve

Validation of the heading model

The contact time and velocity of the *sepak takraw* ball obtained from FEA simulations and experiments were compared, and it is found that the percentage similarity in the contact time and velocity of the *sepak takraw* ball is 93.00 and 95.01%, respectively. This indicates that there is good agreement between the simulation and experimental results, which validates the heading model developed in this study.

Summary of key findings

The key findings of this study are summarized in Table 3. It can be seen that the HIP increases from 11.366 to 13.639 kW when the velocity of the *sepak takraw* ball increases from 13.581 to 15.000 m/s. More importantly, the probability of concussion increases from 39 to 51% even with a slight increase in velocity of the *sepak takraw* ball.

Table 3: Head impact power of *sepak takraw* ball corresponding to a particular velocity and the resultant probability of concussion due to the impact of the ball during heading

Type of heading	Velocity of *sepak takraw* ball (m/s)	Head impact power (kW)	Probability of concussion HIP (%)
Forehead	13.581	11.366	39
	15.000	13.639	51

Conclusion

In this study, the head impact power of a *sepak takraw* ball during heading has been investigated in this study by means of numerical simulations using finite element analysis and experiments. Based on the results, it can be concluded that there is a possibility that the *sepak takraw* players will suffer from mild traumatic brain injuries (MTBI) due to the impact of the *sepak takraw* ball on the players' forehead. According to Newman et al. (2000), the probability of concussion is 39% for *sepak takraw* heading, specifically at the forehead.

Since heading is one of the basic movements to hit the ball during a *sepak takraw* game, which is also the case for soccer as shown by Lipton (2000), it is believed that the players are exposed to a higher risk of suffering from MTBI due to frequent collisions between the players' foreheads and the *sepak takraw* ball. Hence, it is recommended that the players wear protective headbands in order to reduce the impact during heading and prevent the occurrence of MTBI in the long term.

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