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Computational Analysis of Fit Between Human Head Shapes and Taekwondo Headgear

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Abstract: Taekwondo headgear is required equipment for athletes to use in order to compete in any tournament. The headgear is used to lessen the impact of any hit from the opponent. Wearing inadequate headgear can result in a variety of injuries, the most serious of which is unconsciousness. These studies will conduct a 3D anthropometric investigation of the head and face, as well as an analysis of the Helmet Fit Index (HFI) score, in order to determine the suitability of the taekwondo headgear for Malaysian citizens. The research becomes precise and more accurate when using an analytical approach such as software gap analysis and 3D scanning because it is measured in a larger significant number. The results showed that current taekwondo heads produced by manufacturers have a lower fitness level than Malaysian citizen heads. It also shows that some areas of the helmet have less than 20% fitness, particularly in the front and back of the helmet. The findings could be used as data or information to design new taekwondo headgear in the future. This study could also serve as a model for future researchers who want to conduct fitness tests on other headgear using a similar method.

Keywords: Taekwondo Headgear, Helmet Fit Index, 3D Scanning, Gap Analysis

1. Introduction

Taekwondo is the national martial art and sport of Korea with origins dating back at least 1000 years [1]. The word "Taekwondo" is composed of three parts. "Tae" refers to the foot, and to lifting and kicking of the leg. "Kwon" refers to the fist. "Do" refers to the spirit, the method and the procedure [2]. It is practiced in at least 140 countries, and 120 nations are official members of the sports major organizing body, the World Taekwondo Federation (WTF). The WTF was admitted to the International Olympic. Committee in 1980, and taekwondo was a demonstration sport in the 1988 and 1992 Olympic games [1]. Furthermore, competition Taekwondo became an official event in the 2000 Olympics in Sydney, Australia. Taekwondo is

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highly focused on both physical and mental discipline [3].

Taekwondo players must wear protective gear, including headgear, hand guards, foot guards, and groin guards. Without proper protective gear, a player will be barred from participating in a game [2]. Headgear is used in many sports where participants are susceptible to concussive injury [4]. There were widely used by all sport such as football headgear, which have been used since the early days of football, began as a soft leather helmet and transitioned to a hard-plastic shell with energy-absorbing padding in the 1950's. Hockey headgear began to gain popularity in the 1970's [5]. Taekwondo is a physical contact sport between two players. Kicking the head has the highest point and if spinning technique is involved, extra point is awarded. Blows to the head region occur commonly in competition Taekwondo [3]. Taking a head blow will create a heavy injury such as headaches, fatigue, light sensitivity, irritability, loss of temper and anxiety. Wearing a headgear during in a game will reduce all of the injury. However, study have been found out that a poor headgear fit can may increasing the injury receive from a physical contact [6].

2. Materials and Methods

The helmet fit analysis method consisted of several steps (1) finding 8 Malaysian participants (2) Taekwondo head gear were scanned by using high end 3D scanner which generated scan with high accuracy and resolution. (3) both scans will be aligned in a Geomagic Studio 12. (4) several analyses were performed to compute HFI for each participant.

2.1 Materials

Participant's head scan, taekwondo headgear scan and participant wearing taekwondo headgear scan were required in this study. The scanned image was required by using 3D scanner with advanced white light. 8 participants were volunteered in this study. All of them are students from Universiti Tun Hussein Onn Malaysia. Their gender is male with average 23.5 years old.

Table 1: Demographic data for Universiti Tun Hussein Onn Malaysia's student

Participant	Age	Nationality	Gender
A	23	Malaysian	Male
B	23	Malaysian	Male
C	23	Malaysian	Male
D	23	Malaysian	Male
E	23	Malaysian	Male
F	25	Malaysian	Male
G	25	Malaysian	Male
H	23	Malaysian	Male

2.2 Methods

There were three types of scanning procedures, the head scan of the participants, the participants head with headgear and taekwondo headgear. During the scanning process, each participant was being required to wear a swimming cap to avoid hair irregularities. Next, the participant will be asked to sit straight up in a chair and try to maintain their facial expression throughout the scanning process. After that, all mesh will be imported to Geomagic Studio 12 for cleaning. The cleaning is done in order to remove several manifold triangles, to fill the holes, and making the mesh smooth. Figure 1 and figure 2 show the result after the cleaning process is done.

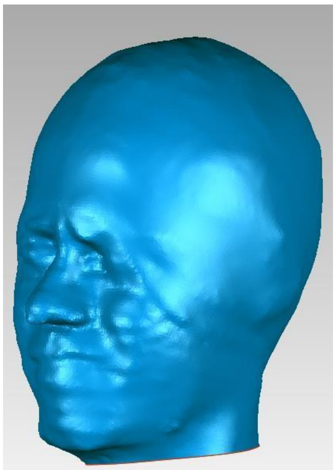

Figure 1: Edited participant's head scan

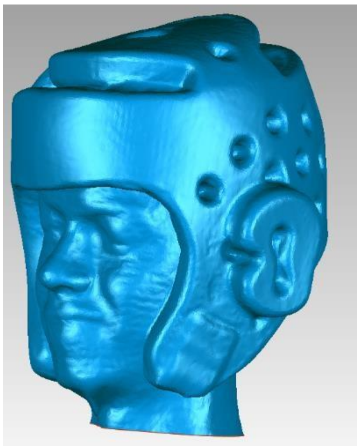

Figure 2: Edited participant with taekwondo headgear

2.3 Scan Alignment

A clean headgear mesh was used of the head scan. The reason is because to analyse the distance between the inner surface of the headgear lining with the head. Rather than physically aligning the two meshes together, we used a third-party scan to correctly position the headgear with the participant's head. The intermediary scan was removed after the two-stage alignment process, and the head and headgear scans were accurately aligned. Figures 3 and 4 depict the process of aligning the participant's head and the taekwondo headgear to the third-intermediate scan, which had previously been scanned separately. Figure 5 shows the final alignment result.

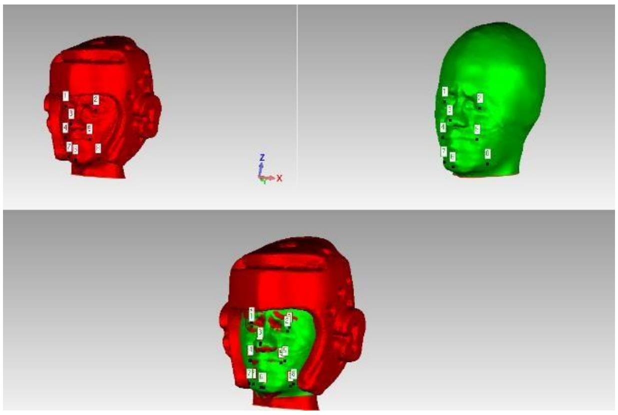

Figure 3: Participant's head, the first stage of alignment

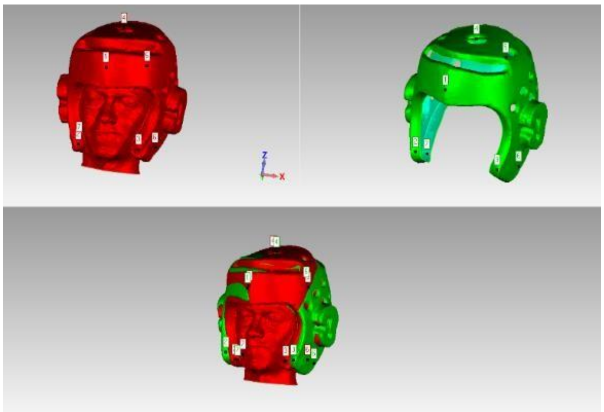

Figure 4: Taekwondo headgear, the second stage of alignment

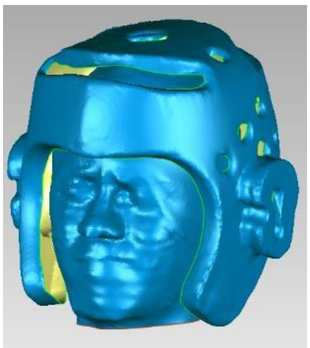

Figure 5: The final result of alignment

2.4 Anthropometric Data

Human pubertal growth occurs on average at the age of 17±2.5 months in the same year for some people and later for others. The chosen participants were all over the adult maximum growth rate and thus suitable for the study. They had an average age of 23.5 years old. The dimension that will be included in the anthropometric study is depicted in Figure 6. Face width (FW), head circumference (CF), Head length (HL), arc length (AL), bitragion width (BW), arc length (AL), and arc length head width (AW) are some of the important parameters studied.

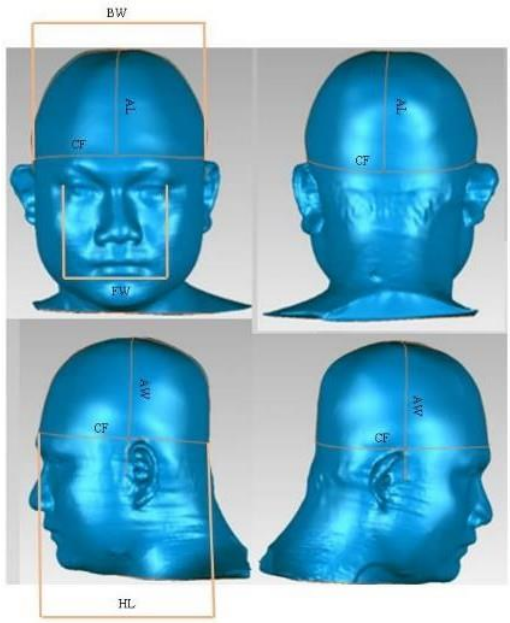

Figure 6: Anthropometric and line dimension figure

2.5 Proportion of Head under Taekwondo Headgear

To provide the best protection, headgear should cover as much of the wearer's skull as possible. Due to the fact that human heads vary in shape and geometry, headgear models on the market have a limited total coverage area for certain human head forms. These would increase the wearer's chances of suffering a concussion. Head Protection Proportion was created as a variable for helmet fit analysis to measure the percentage of the head that is protected.

2.6 Test Area Protected

The test area is created by drawing a line on the edited mesh that follows the guidelines from the 2020 Standard for Protective Headgear: Extend of Protection [7]. The Fore Plane, Transverse Plane, Rear Plane, and Longitudinal Plane were used to calculate the dimensions of the test line. The line was then joined together to form a protective area for the human skull. The lining of the test area, as well as the dimensions required by the standard, are depicted in Figure 7 and Figure 8. The protected area is highlighted with red.

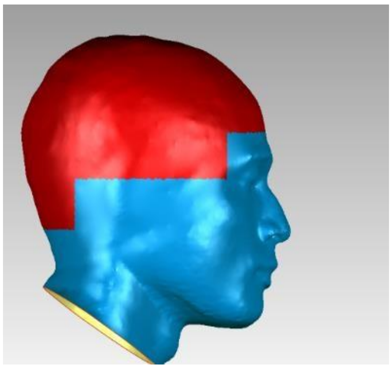

Figure 7: Clean up Test Line Dimension for Test Area

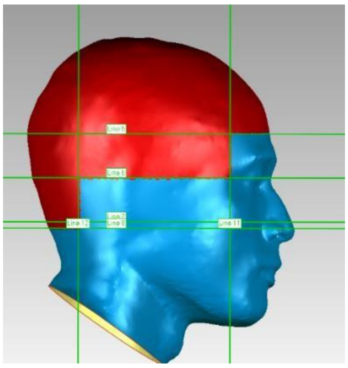

Figure 8: Dimension Drawn on Participant Mesh

2.7 Actual Area Protection

The area projected on the helmet's boundary to the participant's head determines the actual area of protection. Geomagic Studio 12 will then compute the area to determine how much of the participant's head is actually protected by the taekwondo headgear. Figure 9 shows the actual area protection projected to participant's head.

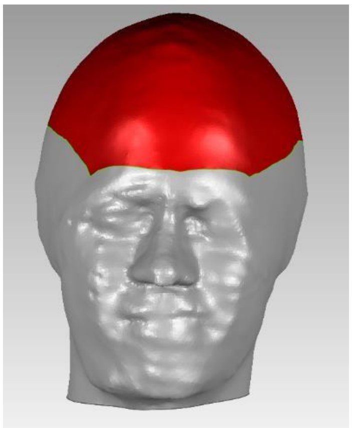

Figure 9: Area Taekwondo Headgear Projected to Participant's Head

2.8 Gap Analysis

Under the digitised shape editor, CATIAV5R20 is used for gap analysis in deviation analysis. Check for any errors that may have occurred during the analysis by importing the edited part into the software. The deviation analysis could be used to determine the standoff distance and gap uniformity after the repair process. Figure 10 shows the mesh imported from the distance analysis tool which is Geomagic studio software to gap analysis tool which is CATIAV5R20 for analysis. Figure 11 depicts the gap analysis of the participant's head and the inner side of the taekwondo headgear. The shortest and longest distances between the two meshes will be revealed by these analyses. Figure 11 depicts the gap analysis from the side view. Figure 12 show the gap analysis value.

Figure 10: Importing Mesh to CATIAV5 for Analysis

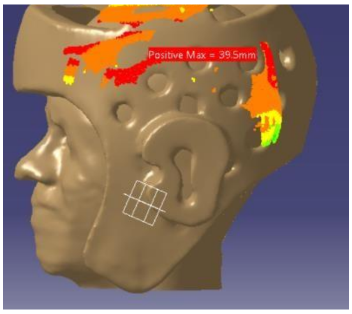

Figure 11: Analysis from Side View

Figure 12: Gap Analysis Value

2.9 Helmet Fit Index

Previous researchers at Melbourne's School of Manufacturing Engineering, Mechanical and Aerospace developed the Helmet Fit Index (HFI), which is a fit score for a specific helmet model and a human head. On a scale of 0 (extremely poor fit) to 100 (perfect fit), the index is defined. There were two types of data generated as a result of this study: an exponential distribution and a linear distribution. The study will compare the fit scores of both distributions to see which one has the best fit.

$$f(x,\lambda) = \begin{cases} \lambda \times \exp(-\lambda x) & x \geq 0 \\ 0 & x < 0 \end{cases} \qquad \text{Eq. 1}$$

The following is the definition of the probability density function, f, of an exponential distribution that will be used: λ is the rate parameter, which is a distribution parameter. As the fit improves, ⍰ will approach zero as a function of Standoff Distance, Gap Uniformity, and Head Protection Proportion. To allow thermal control to flow through the helmet, the optimal Standoff

Distance value is set to be greater than 0. Previous research has determined that the ideal value is between 4 and 8mm. If the standoff distance is uniform across the entire liner surface of the helmet and the head surface mesh, the helmet's fit improves. As a result, there will be less deviation from the mean. As a result, the uniformity of the gap will be approaching zero.

When the HPP approaches 1, which corresponds to a higher ration of area coverage protection provided by the helmet, another parameter that improves fit is the HPP. When the parameters are added together, the value of x is

$$HFI = \begin{cases} 100 * \exp\left(0.13 - \frac{|SOD-6|}{15} - \frac{0.12GU}{HPP}\right), & 4 > SOD > 8 \\ 100 * \exp\left(\frac{0.12GU}{HPP}\right), & 4 \le SOD \le 8 \end{cases} \qquad \text{Eq. 2}$$

α and β are coefficient parameters that affect HFI and are important to GU and HPP. Where α and β were coefficient parameters calculated as α =2/ 3 and β =6/5, respectively. Following previous research, we chose 0.1 as the value for the HFI and multiplied the function by 100. When the functions x and will λ are swapped out, the result is:

$$HFI = \begin{cases} 100 * \exp\left(0.13 - \frac{|SOD-6|}{15} - \frac{0.12GU}{HPP}\right), & 4 > SOD > 8 \\ 100 * \exp\left(\frac{0.12GU}{HPP}\right), & 4 \le SOD \le 8 \end{cases} \qquad \text{Eq. 3}$$

Through calculation, we can determine the global fit score index for each participant using this formula. Similarly, an HFI score for local regions was created using only the local SOD and GU. The following is the proposed equation:

$$HFI = \begin{cases} 100 * \exp\left(0.13 - \frac{|SOD-6|}{15} - \frac{0.12GU}{HPP}\right), & 4 > SOD > 8 \\ 100 * \exp\left(\frac{0.12GU}{HPP}\right), & 4 \le SOD \le 8 \end{cases} \qquad \text{Eq. 4}$$

3 Results and Discussion

8 participants were all males with average aged of 23.5 years old, students from Universiti Tun Hussein Onn Malaysia were volunteered to took part in this study. Each participant was asked to wear a same size of taekwondo headgear which is medium size. Table 2 shows the result for the GU, HPP, SOD, x, hair thickness and HFI for each participant. The parameter means and standard deviations are presented in the last rows of Table 2. Fit parameter for five local region are presented in Table 3 with respective SODs, Gus, and HFIs.

Table 2: Table Results of Analysis HFI Global

Participant	SOD (mm)	GU (mm)	Test Area (m^2)	Protection Area (m^2)	HPP	x	HFI

A	26.3	5.32	0.066338	0.049354	0.74	19.561	12.48
B	22.8	6.71	0.064145	0.049728	0.78	19.266	13.15
C	27.5	7.23	0.059873	0.050476	0.84	21.991	9.71
D	22.7	6.22	0.069817	0.056059	0.80	18.116	14.76
E	22.4	5.87	0.067232	0.054314	0.81	17.359	15.96
F	23.9	5.92	0.071081	0.051059	0.72	19.430	12.84
G	23.2	5.21	0.067032	0.053922	0.80	16.892	16.63
H	20.4	6.16	0.063807	0.056264	0.88	15.823	18.86
Mean	23.65	6.08	0.066166	0.052647	0.80	18.555	14.29
Std Dev	2.26	0.67	0.003559	0.002822	0.05	1.925	2.85

Table 3: Table Results of Analysis of HFI Global

Participant	Front			Top			Right		
	SOD (mm)	GU (mm)	HFI	SOD (mm)	GU (mm)	HFI	SOD (mm)	GU (mm)	HFI
A	30.6	4.19	13.36	23.5	3.74	22.64	27.6	2.88	19.10
B	23.6	6.77	15.63	27.8	3.09	18.38	25.6	3	21.51
C	25.8	5.96	14.88	20.6	3.48	28.34	31.5	3.23	14.12
D	21.3	6.64	18.51	16.6	2.69	40.68	25.3	3.92	19.65
E	23.9	6.77	15.32	18	4.36	30.32	25.2	3.04	21.99
F	24.2	6.22	16.05	20.3	2.76	31.52	27.6	3.61	17.50
G	22	6.8	17.33	19.3	2.61	34.31	27.6	3.02	18.78
H	21.7	6.61	18.09	15.9	3.25	39.85	24.7	3.53	21.43
Mean	24.14	6.25	16.15	20.25	3.25	30.75	26.89	3.28	19.26
Std Dev	3.01	0.88	1.74	3.89	0.60	7.74	2.22	0.37	2.60

Table 4: Table Results of Analysis of HFI Global

Participant	Left			Back		
	SOD (mm)	GU (mm)	HFI	SOD (mm)	GU (mm)	HFI
A	36.3	1.51	12.60	26.7	5.65	14.54
B	30.4	2.8	16.00	20.6	6.46	19.82
C	29.5	1.57	19.69	33.9	6.67	7.96
D	23	1.76	29.68	27.5	4.43	15.96
E	31.2	3.02	14.77	23	5.25	19.53
F	30.1	2.94	16.05	24.2	6.43	15.65
G	23.5	1.99	27.93	26.3	3.7	18.87

H	26.2	2.09	23.05	22.1	6.18	18.55
Mean	28.78	2.21	19.97	25.54	5.60	16.36
Std Dev	4.40	0.62	6.32	4.14	1.07	3.92

3.2 Discussions

From Table 2, the average Helmet Fit Index percentage is 14.29%, which is less than 50% and has a standard deviation of only 2%. Participant C has an extremely poor fit (HFI = 9.71%) with a large SOD and GU, according to data from table 4.7. However, in table 4.7, the head test area for participant C who was wearing headgear is the second highest with a higher value of GUs indicating a non-uniform distribution of the gap along the length of the head. Only 8 Malaysian citizens differ in shape, size, and geometry, according to the standard deviation of only 2.85%.

Table 3 shows that the distribution of local gaps varied slightly between the five helmet regions, with the left region (SOD) having the most gaps compared to the others. The top region has the highest HFI score of all the regions, as can be seen. HFI scores of 16.15 and 16.36 are perceived to be lower in the front and back regions, respectively. Because most people's heads are symmetrical on both sides, the left and right regions have nearly identical scores.

The sample size of participants should be much larger in order to obtain more accurate mean and average HFI information to represent the population. A photogrammetry scanner with a static subject produces a smoother mesh than the current portable 3D scanner from sense. Other better 3D scanner tools would reduce editing work and provide more accurate results by smoothing the mesh of the participant. Furthermore, the sense 3D scanner can only scan the outside of the headgear; better 3D scanner tools would be required to scan both the outside and inside of the headgear for a better mesh and more accurate results. This research employs antiquated software. Because of the new features provided by updated software, it is possible that using it will improve the accuracy. Finally, this research concentrates on headgear and head measurement. Future researchers could apply the same method to other parts of the body and their equipment to see if they can improve the equipment's safety or comfortability.

4. Conclusion

The paper focus on taekwondo headgear fit that influences the wearer’s safety from the impact of the fight during taekwondo match or tournament. The current taekwondo headgear, according to the findings, would not fit into a Malaysian's head. Without an analytical approach, it is clear that there is a significant gap when putting on the headgear, particularly in the front region. The anthropometric data leads to the conclusion that participant length and width vary. Some parameters may be longer for a particular participant, while others may be shorter. Despite its flaws, the HFI method provided accurate and efficient data for analysing, comparing, and improving current taekwondo headgear for taekwondo athletes. More research is required to gain a better understanding of the HFI prospective

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