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The Fit of Safety Helmet Among Female

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Abstract: Safety helmets are used in many fields of endeavour such as police work, fire fighting, construction work, and sports as well as by aircraft crew members. Safety helmets are protective equipment used to reduce or prevent the impact on the head when an object is hit or dropped. With the proper and right way of helmet used, it acts as a protection tool for workers and can help prevent and control collateral damage. This pilot research study the fit and comfort perception of safety helmet among women participants. The method used in this reseach was collecting data from questionnaires, scanning the participants head when wearing and not wearing a safety helmet, post-scanning data processing and data of gap analysis, proportion of head under helmet protection and HFI calculation. 5 out of ten participants were feeling discomfort when wearing safety helmets. The left, right, top and front regions of the head have a larger gap compared to the back region. The overall HFI score was middle fit.

Keywords: 3D Anthropometry, Safety Helmet, Fit Assessment, HFI

1. Introduction

Safety helmets are widely used throughout the industry and especially in the construction industry and mining industry. Safety helmets are typically manufactured from hard plastic material with the inside consist of a webbing strap which extend over the user's head and the back of the helmet is an adjustment strap to allow the helmet to be properly fit to the user [1]. Safety helmets are protective equipment used to reduce or prevent the impact on the head when an object is hit or dropped. With the proper and right way of helmet used, it acts as a protection tool for workers and can help prevent and control collateral damage. Safety helmets act as the first line of defence against head injuries, if it is

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worn properly. The most important tasks of the safety helmet is protection of the user's head against impact caused by objects falling or hitting the head with hazardous element. It is safe to say that a safety helmet could save lives and reduces the risk of brain injury. Most head injuries can be avoided if the right head protection is chosen, used and maintained [2].

Some workers did not wear safety helmets due to various reasons related to comfort of the helmets. Research shows that over 15.0 % of workplace injuries are caused by not wearing a proper safety helmet [3]. Belayutham and Ibrahim [4] stated that the construction industry in Malaysia is the third most dangerous industry with the highest death rate compared to other industries. This is mainly due to the effect of not wearing a proper safety helmet. In 2015, the Department of Occupational Safety and Health (DOSH) stated that of the 237 occupational accidents reported in construction in Malaysia, 88 were fatal with a fatality rate of 4.84 deaths per 100,000 workers [4].

Each human head is very different. Although two people have the same head circumference, they may have different relative lengths and widths, and of course have different head topography. Conventional helmet sizes, small, medium, large, large, etc., are generally based on head circumference. Few studies have been conducted on the issues of safety helmets. Study by [5] stated that wearing a wrongly sized helmet could compromise its intended safety performance and lead to feelings of discomfort. Discomfort of the helmet is likely to negatively impact the readiness to wear the protective headgear, which could lead to severe head injuries or even fatal consequences in the event of a fall [6]. Hao et al. [3] has addressed the shortage of safety helmet comfort research and focused on finding the fit index that affects the safety of safety helmets in order to improve the comfort of the safety helmet.

This research analyse the gap or fit between the helmet and the head surface covered by the safety helmet using the helmet fit index (HFI). HFI is a method that combines 3D anthropometric data and computational tools. HFI can improve the sizing and the fit of a safety helmet and if accidents happen, the fit of the helmet can reduce injuries especially fatal injury. The research was done by collecting data from questionnaires, scanning the participants' heads when wearing and not wearing a safety helmet, post-scanning data processing and data of gap analysis, proportion of head under helmet protection and HFI calculation

2. Materials and Methods

The method used to complete this research are explained below. It starts with collecting data from survey, 3D scanning of participants head when wearing and not wearing a safety helmet, post-scanning data processing and data of gap analysis using Geomagic and CATIA software, and HFI analysis.

2.1 Questionnaires Data Collection and Analysis

Ten women participants from University Tun Hussein Onn Malaysia (UTHM) participated in this study. All participants who volunteer to do this study were asked for consent before starting the experiments.

The structure of the questionnaire is using a quantitative method so that the result is easy to summarize, compare and generalize. A Likert-type of questions was used in most of these questionnaires, respondents will be asked to select one of several five or ten responses that are ranked in order of strength. Likert scales are very frequently used to measure constructs such as satisfaction rates, attitudes towards different things, measure opinions and beliefs [7]. The questionnaire was split into five categories which are personal details of participants, the helmet usage of participants that wear safety helmets, issues of safety helmet, the fit requirements of safety helmet and helmet fit assessments.

To determine the minimum or maximum scale of the 5-point and 10-point type scale, the average scale was calculated by using Eq. 1. The amount of average scale was determined as 1 to 1.80 represents strongly disagree, 1.81 until 2.60 represents do not agree, 2.61 until 3.40 represents (true to some extent), 3.41 until 4.20 represents agree and 4.21 until 5.00 represents strongly agree [7].

$$\text{Average Scale} = \frac{(\text{number of people who selected response n}) \times (\text{weighting of response n})}{(\text{total number of respondents})}$$

Eq. 1

2.2 3D Scanning

3D Systems Sense Scanner (shown in Figure 1) was used to capture a single 3D head scan of each participant. This scanner is easy, fast, portable and practical. 3D Systems Sense Scanner also offers colourful 3D scanning for use in businesses or academic institutions.

Figure 1: 3D Systems Sense Scanner

During the scanning procedure, the participants were asked to sit upright on a chair and look at a fixed point on the wall in front of them, while maintaining a neutral facial expression. Next, the participants were asked to wear a wig cap that compressed their hair in order to minimize surface irregularities and expose the actual shape of their heads. After that, the researcher will perform the scan by moving around the seated participant. When the scan was finalized, it were exported as a Standard Triangle Language or Standard Tessellation Language (STL), Polygon File Format or Stanford Triangle Format (PLY) or Standard 3D Image Format (OBJ) file. Then the scan mesh was imported to Geomagic Studio software for further processing.

2.3 Post-scan Data Processing

First the scanning was cleaned and repaired. The mashes of the 3D head scans were imported to Geomagic Studio software for post-processing. The post-processing procedure begins by repairing the mesh, which includes filling holes, removing spikes, and repairing edges. Hair bumps and fabric folds was removed and the mesh was smooth by decreasing angles between individual polygons. The maximum deviation distance for non-hair bumps or fabric fold areas was set to ± 50 mm [8].

Next, the participants' head were aligned to a generic axis system, so the participant's head were in a straight position as the safety helmet. Firstly, create the SA-plane as symmetrical to the head mesh using an automated tool in Geomagic software. Secondly, create HC-plane by using the outer corners of the eye sockets to make the plane approximately horizontal. Thirdly, the BCA-plane was created as perpendicular to the two existing planes, positioned according to the regions.All of the plane was shown in Figure 2. Lastly, an orthogonal axis system will be created for each participant by using the position of the three planes, which was subsequently aligned to the global axis system within Geomagic software [8].

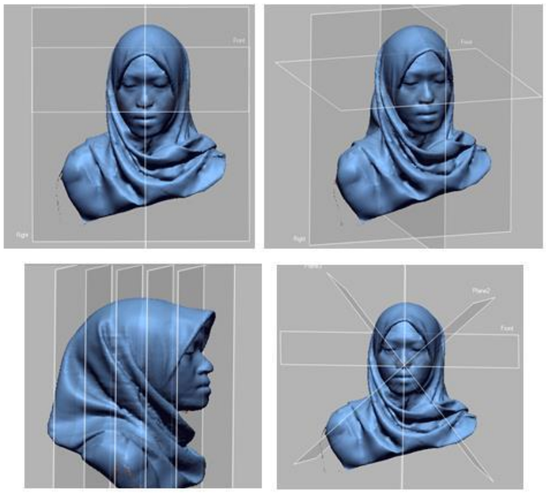

Figure 2: Reference planes created for head scan alignment (HC-plane, BCA-plane and SA-plane)

To have a better shape of the head, a hair thickness offset (HTO) were performed for each participant individually [9]. The align head scans were imported into the software, where distance analysis tool was used to measure the gap between the head and surface scans in helmets.

2.4 HFI Analysis

The alignment of the helmet was performed by creating an independent helmet axis system, which enabled a fine adjustment of the helmet's position on the participants' heads within the post processing software as shown in Figure 3 and Figure 4. This procedure was implemented in an attempt to address limitations associated with using only a reference scan with the participants wearing the helmet, as reported in [10].

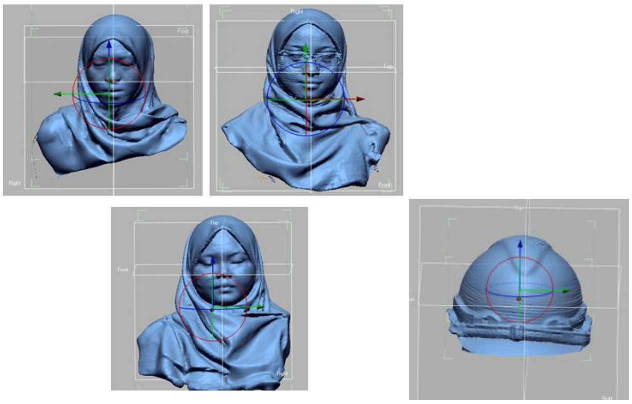

Figure 3: Alignment of participant's head and safety helmet on the reference axis

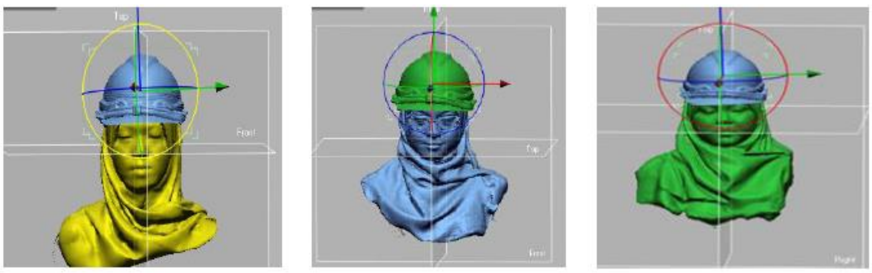

Figure 4: Alignment of safety helmet on participant's head

Ellena et al. [9] method for calculating the HFI has been adopted in this research. First, the gap analysis was conducted. The CATIA V5 remote sensing tool was used to determine the gap distribution between the two inner liner surface meshes and participant' head mesh. Secondly, the proportion of head under helmet protection was conducted. The last variable included in the HFI calculation was the proportion of the head surface area that was covered by the helmet. Ellena et al. Ellena et al. [9] stated that the new minimum surface area and ideally should be under helmet protection. By projecting the border of helmet liners and defining the minimum surface area on the head meshes, the proportion head under helmet protection for each of the two liners can be calculated. This value is called Head Protection Proportion (HPP). The SOD, GU, and HPP value were included so that the HFI value can be calculated. To provide a "fit score", which is the range from 0 (excessively poor fit) to 100 (perfect fit) is according to Eq. 2:

$$\mathrm{HFI} = \{100 \exp\left(0.13 - \frac{|\mathrm{SOD}-6|}{15} - \frac{0.12\mathrm{GU}}{\mathrm{HPP}}\right), \text{for } 4 > \mathrm{SOD}$$
$$> 8\ 100 \exp\left(-\frac{0.12\mathrm{GU}}{\mathrm{HPP}}\right), \qquad \text{for } 4 \leq \mathrm{SOD} \leq 8$$

Eq 2

HFI were calculated for each region of the inside liner based on computations of the local SOD and GU according to Eq. 3:

$$\mathrm{HFI} = \{100 \exp\left(0.13 - \frac{|\mathrm{SOD}-6|}{15} - 0.12\mathrm{GU}\right), \text{for } 4 > \mathrm{SOD}$$
$$> 8\ 100 \exp(-0.12\mathrm{GU}), \qquad \text{for } 4 \leq \mathrm{SOD} \leq 8$$

Eq 3

3. Results and Discussion

The questionnaires were answered by ten participants. The range of age is between 22 to 24 years old and most of the participants were Malay and only one was Iban race. Table 1 shows the usage of safety helmets at construction sites. An average of 1.8 of participants wears safety helmets at the construction site. This average scale shows that, participants worn safety helmet very often at the construction site. The main reasons participants do not want to wear safety helmets were because inconvenience, discomfort, helmets do not fit properly and others as shown in Table 2. Five out of ten participants were feeling discomfort when wearing safety helmets, two participants felt it did not fit properly and three participants were unaware of the importance of wearing a safety helmet.

Table 1: Helmet usage (1: always - 5: never)

Question/Scale	1	2	3	4	5	Average Scale
How often do you wear safety helmet at site?	4	4	2	0	0	1.8

Table 2: Reasons for not wearing safety helmet

Question/Reason	Inconvenience	Discomfort	Does not fit properly	No size allotted	Unaware the importance of safety helmet
Main reason for not wearing a safety helmet (if applicable)?	0	5	2	0	3

Table 3 shows the issues of the safety helmet. Participants find that the safety helmet was available in their size with an average scale of 4.5. Safety helmets sizes are not difficult to find since the average scale was at 2.0. An average of 3.5 participants agreed that safety helmets were designed based on Malaysian anthropometric data. The data shows that there was a gap between participants' head and safety helmet with an average of 3.9 participants agreed to have a gap when wearing a safety helmet.

Table 3: Issues of safety helmet (1: very disagree - 5: very agree)

Questions / Scale	1	2	3	4	5	Average Scale
Does the safety helmet available in your size?	0	0	0	5	5	4.5
Is it difficult to find your helmet size?	4	4	1	0	1	2.0
Does the safety helmet was designed based on Malaysian anthropometric data?	0	2	3	3	2	3.5
When you wear a safety helmet, does it have a gap between the head and the helmet?	0	2	0	5	3	3.9

The fit requirement of the safety helmet is shown in Table 4. Participants feeling satisfied with the degree of pressure on their head when wearing a safety helmet with an average scale of 7.9. It was important to have an ideal degree of pressure because when high pressure on their heads it can cause feels uncomfortable while wearing safety helmets on site [11-13]. Almost all participants agreed on the importance of achieving the fit for safety helmet.

Table 4: The fit requirement of safety helmet (1: very poor - 10: very good)

Questions / Scale	1	2	3	4	5	6	7	8	9	10	Average Scale
Please rate your ideal degree of pressure on your head when wearing a safety helmet.	0	0	0	0	1	2	0	3	2	2	7.9
How would you rate the importance of achieving your ideal fit in a safety helmet?	0	0	0	0	0	0	0	3	4	3	9.0

Table 5 shows the helmet fit assessments test. The tests were conducted on seven participants by asking them to wear a safety helmet that was given to them. Five out of seven participants with an average scale of 2.9 feels comfortable with the overall fit assessment of the safety helmets. The fit of top and front region safety helmets have the same value of comfort which were six participants with an average scale of 3.4. While the back region fit safety helmet has five participants with an average scale of 2.9 are comfortable.

Table 5: Helmet fit assessment (1: very uncomfortable - 5: very comfortable)

	Assessment / Scale	1	2	3	4	5	Average Scale
1.	Overall fit assessment value	0	0	1	5	1	4.0
2.	Top region fit	0	1	0	6	0	3.7
3.	Front region fit	0	0	1	6	0	3.9
4.	Back region fit	0	0	1	5	1	4.0

3.1 Analysis of 3D Anthropometry: Data Collection and Processing

The gap between three participant's head and safety helmet is shown in Table 6. The distance value for top and front was higher on participant C, right and left was higher on participant B and for the back gap participant A has higher value. The value of HFI in Table 7 shows that participant A has the highest fit compared to participant B and C.

Table 6: The distance between participants head and safety helmet

Participants	Top (mm)	Front(mm)	Right(mm)	Left(mm)	Back(mm)
A	9.51	10.21	13.17	15.10	7.0
B	12.92	13.64	15.97	15.12	9.51
C	15.57	14.67	12.32	13.30	5.33

Table 7: Values of SOD, GU, HPP and HFI of each participant

Participants	SOD (mm)	GU (mm)	HPP	HFI	Inside linear of HFI
A	11.00	3.18	0.95	62.12	59.76
B	13.43	2.50	1.42	42.86	46.84
C	12.24	4.06	1.18	56.76	61.14

4. Conclusion

Safety helmet is protective equipment that is worn by the workers at construction to reduce or prevent the impact on the head when an object is hit or dropped. This research determine the fit index of safety helmet among ten female participants at UTHM. In this research, the factors affecting the comfort of safety helmets are the fit of the safety helmet. The results show the right, left, top and front regions have larger gap compared to the back region. The distance value for top and front region was higher on participant C, right and left was higher on participant B and for the back gap, participant B recorded a higher value. A high value of gap decreases the HFI value. It can be conclude that the participant's head has a middle fit score of HFI. Although the questionnaires result shows no significant issue with the safety helmet, the HFI value showed mid fit score of HFI. This indicate that the safety helmet does not fit properly on participant's head.

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References

[1] Fernando. (2019). *(12) United States Patent*. *2*(12).

[2] Baszczyński, K. (2018). Effects of falling weight impact on industrial safety helmets used in conjunction with eye and face protection devices. *International Journal of Occupational Safety and Ergonomics*, *24*(2), 171–180. https://doi.org/10.1080/10803548.2017.1373987

[3] Hao, W., Shan, L., Yang, W., Jingjing, W., Chenyan, L., & Yun, Z. (2019). Analysis of the Influence Factors of Safety Helmet Comfort. IOP Conference Series: Earth and Environmental Science, 218(1). https://doi.org/10.1088/1755-1315/218/1/012076

[4] Belayutham, S., & Ibrahim, C. K. I. C. (2019). Barriers and strategies for better safety practices: The case of construction SMEs in Malaysia. Construction Economics and Building, 19(1), 1–20. https://doi.org/10.5130/AJCEB.v19i1.6331

[5] Pang, T. Y., Lo, T. S. T., Ellena, T., Mustafa, H., Babalija, J., & Subic, A. (2018). Fit, stability and comfort assessment of custom-fitted bicycle helmet inner liner designs, based on 3D anthropometric data. Applied Ergonomics, 68(February 2016), 240–248. https://doi.org/10.1016/j.apergo.2017.12.002

[6] Bandmann, C. E. M., Akrami, M., & Javadi, A. A. (2018). An investigation into the thermal comfort of a conceptual helmet model using finite element analysis and 3D computational fluid

dynamics. International Journal of Industrial Ergonomics, 68(October 2017), 125–136. https://doi.org/10.1016/j.ergon.2018.07.004

[7] Beglar, D., & Nemoto, T. (2014). Developing Likert-scale questionnaires. JALT2013 Conference Proceedings, 1–8.

[8] Skals, S., Ellena, T., Subic, A., Mustafa, H., & Pang, T. Y. (2016). Improving fit of bicycle helmet liners using 3D anthropometric data. International Journal of Industrial Ergonomics, 55, 86–95. https://doi.org/10.1016/j.ergon.2016.08.009

[9] Ellena, T., Subic, A., Mustafa, H., & Pang, T. Y. (2016). The helmet fit index - an intelligent tool for fit assessment and design customisation. Applied Ergonomics, 55, 194–207. https://doi.org/10.1016/j.apergo.2016.02.008

[10] Meunier, P., Tack, D., Ricci, A., Bossi, L. & Angel, H. 2000. Helmet accommodation analysis using 3D laser scanning.

[11] Baszczyński, K. (2018). Effects of falling weight impact on industrial safety helmets used in conjunction with eye and face protection devices. International Journal of Occupational Safety and Ergonomics, 24(2), 171–180. https://doi.org/10.1080/10803548.2017.1373987

[12] Ellena, T. (2017). Automatic Parametric Digital Design of Custom-Fit Bicycle Helmets based on 3D Anthropometry and Novel Clustering Algorithm.

[13] Kim, S. H., Wang, C., Min, S. D., & Lee, S. H. (2018). Safety helmet wearing management system for construction workers using three-axis accelerometer sensor. Applied Sciences (Switzerland), 8(12), 1–15. https://doi.org/10.3390/app8122400