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Head Anthropometric of Malaysian Male Adults Using 3D Scanning

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Abstract

Safety helmets are essential for protecting individuals in high-risk industries such as construction, sports, and manufacturing, where head injuries are common. Despite their importance, poor helmet fit is widespread, primarily due to a lack of consideration for anthropometric diversity, which reduces their effectiveness and compromises safety. Anthropometry, the study of human body measurements, played a critical role in this research. Current helmet designs are predominantly based on Western anthropometric data, which fail to accommodate the unique head shapes of Malaysians. To bridge this gap, the study involved 3D scans of 100 Malaysian male participants at UTHM, capturing key anthropometric dimensions such as head circumference, width, and length. These measurements were taken with and without helmets to thoroughly analyze fit discrepancies. The findings highlighted significant anthropometric variations within the population, revealing that many existing helmets did not provide a proper fit. This study emphasizes the importance of incorporating localized anthropometric data in helmet design, offering a solution that improves comfort, enhances safety, and reduces the likelihood of head injuries.

1. Introduction

The assessment of helmet fit has become increasingly crucial in raising personal protective equipment standards, particularly in construction, sports, and manufacturing [1]. The effectiveness of a helmet largely depends on a secure, well-fitted design that accommodates the user's specific head shape and size [2]. This study proposes a method combining 3D scanning and anthropometric analysis to refine helmet sizing and fit for the Malaysian population, which differs in head characteristics from Western populations [3]. This research aims to create a more precise sizing system that enhances helmet comfort and safety by measuring head dimensions and clustering head shapes.

Accurate helmet sizing is essential for proper head protection across various industries, where helmets are crucial in reducing head injury risks [4]. Current helmet sizing standards, however, are often inadequate for some populations, particularly in regions like Malaysia, where local head shapes and dimensions differ significantly from Western counterparts [3]. Improper helmet fit, often caused by generalized sizing standards, can result in discomfort, reduced stability, and compromised safety, which may discourage regular use of helmets by workers and athletes alike [1][5]. Anthropometry, the science of measuring human body dimensions, provides a foundation for understanding these size differences [3][6]. Anthropometric studies focus on obtaining and analyzing detailed body measurements, which are then used to enhance the ergonomic design of protective gear. In helmet design, critical dimensions such as head circumference, width, and length are essential to balance comfort and protection [7][8]. Traditional sizing techniques often rely on manual measurements, which may be limited in addressing diverse head shapes [6-10]. With technological progress, 3D scanning has emerged as an effective tool, allowing for detailed head shape analysis and a data-driven approach to assessing fit [9][10]. This study uses 3D scanning technology and anthropometric data to evaluate head dimensions specific to Malaysian users. By applying clustering algorithms to classify head shapes, the research seeks to develop a customized helmet-sizing system tailored to the local population. This approach aligns helmet design more closely with the users' physical characteristics, improving safety and comfort. The findings from this anthropometry study aim to support enhanced helmet standards, leading to increased compliance and protection for Malaysian helmet users across multiple sectors.

The literature highlights significant helmet fit and sizing gaps, especially for diverse populations. Traditional helmet sizing methods often rely on general measurements that may not fully account for head shape and size variations across different demographic groups [6]. This issue is particularly evident in Malaysia, where helmet designs based on Western anthropometric data may not effectively fit local users, leading to discomfort and decreased safety [3][6]. Anthropometry studies provide a critical framework for understanding these differences. Traditional anthropometric approaches in helmet sizing typically focus on manual head circumference, width, and length measurements [6][9]. However, these methods lack precision and do not fully capture individual variation. Recent developments in 3D scanning technology offer a solution by providing detailed, three-dimensional measurements encompassing the entire head contour [10]. This comprehensive approach to understanding head dimensions is essential for designing comfortable and protective helmets [11]. A critical method for improving helmet fit involves clustering algorithms to group head shapes based on anthropometric data [12]. Research shows that clustering combined with 3D scanning can produce more accurate sizing systems tailored to specific population groups. Studies indicate that such tailored systems result in helmets with enhanced fit, stability, and user comfort [13]. Additionally, the Helmet Fit Index (HFI), which evaluates fit quality based on factors like standoff distance and gap uniformity, provides a quantitative measure of helmet compatibility across varied head shapes [14-16]. Overall, the literature emphasizes the value of regional anthropometric data in designing effective helmets [17]. By employing 3D scanning and clustering techniques, this study aims to establish a customized sizing system for Malaysian users, potentially setting a new standard for helmet fit assessment and manufacturing tailored to specific demographic needs.

2. Methodology

2.1 3D Scanning and Post-processing

A sample size of 100 participants took part in this study, and their head shapes were captured using a portable 3D RealSense 2 scanner. They were instructed to sit still and upright during scanning, maintaining their normal facial expressions. To minimize hair interference, they were required to wear thin hair caps.

Fig. 1 *Process of 3D scanning of participant*

This study utilized the design software application to post-process head scan images. Initially, the scans displayed several imperfections, which were addressed through various corrective measures. The scans were first smoothened to eliminate irregularities. Large holes in the scans were carefully repaired individually, while smaller holes were automatically filled using the application's fill tools. The regions affected by the creases from the hair cap, which participants wore to compress their hair during scanning, posed significant difficulties. These were precisely removed and seamlessly reconstructed using the tangential holes fill and defeature tools. The mesh doctor tool rectified non-manifold edges, self-intersections, highly creased edges, spikes, and small disconnected components. Due to the scanner's inability to accurately detect human hair, participants' requirement to wear thin hair caps during scanning led to additional surface glitches at the interface between the hair cap and the head. These unwanted areas were modified using the defeature tool. An automated fill hole function was applied for smaller imperfections like minor holes, whereas larger holes required more intricate editing using partial fill and bridge fill-up tools. Fig. 2 showcases the processed head scan images of the participants involved, illustrating the effectiveness of these post-processing techniques in creating clean and accurate 3D head models.

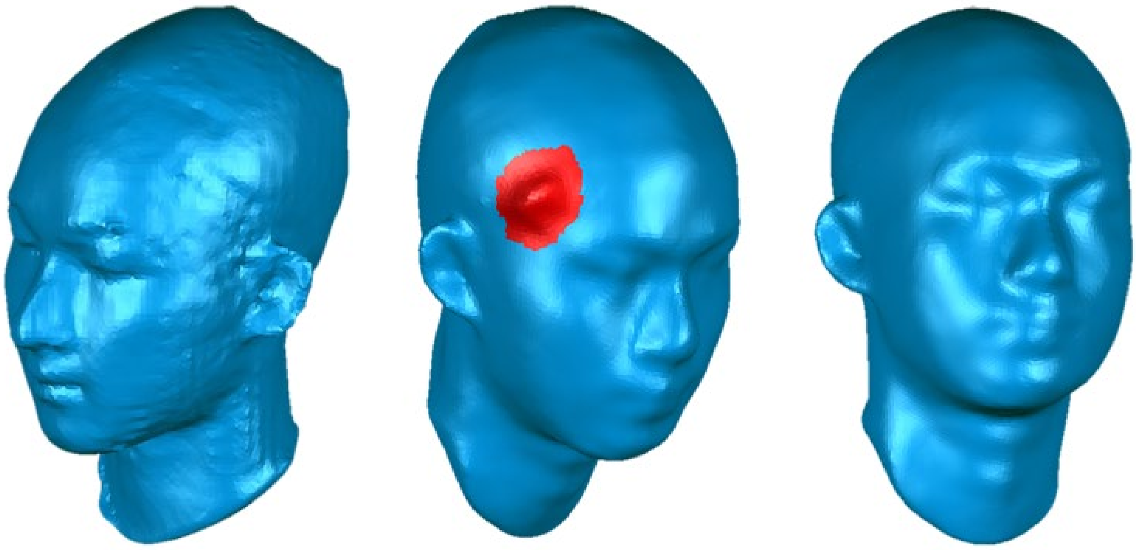

Fig. 2 *Post-processing of 3D head scan*

2.2 Anthropometry Measurement

The anthropometry method for this study began with selecting 100 Malaysian male participants to represent the target demographic. Advanced 3D scanning technology was then utilized to capture precise head measurements, ensuring the accuracy of the collected data. The scanning process involved recording participants' head dimensions, such as circumference, width, and length, both with and without helmets, to assess fit and identify discrepancies. This detailed measurement process provided a comprehensive dataset that accurately reflected the participants' head shapes and sizes. The study established a solid foundation for developing a helmet-sizing system tailored to the Malaysian population by systematically recording and analyzing this anthropometric data.

Anthropometric measurement involves systematically collecting and analyzing human body dimensions and physical characteristics. It encompasses the quantitative assessment of various parameters such as height, weight, body circumference, and limb lengths to understand human size, shape, and variability. An alignment method was devised to establish consistent positioning and orientations of head meshes. The process is initiated by defining a standardized axis system for each scan. Initially, the Sagittal Arc plane (SA plane) is generated to align with the head symmetrically (Fig. 3(green)). Next, the Head Circumference plane (HC plane) is positioned, leveraging the outer corners of the eye sockets to approximate a horizontal orientation, then adjusted to span slightly above the glabella and near the top of the occipital bone (Fig. 3(blue)). Lastly, the Bitragion Coronal Arc plane (BCA plane) is established perpendicular to the SA and HC planes, positioned relative to the Tragions (Fig. 3(red)). Subsequently, an orthogonal axis system is constructed using these plane positions, which is then aligned with a standard axis system integrated into the software [18].

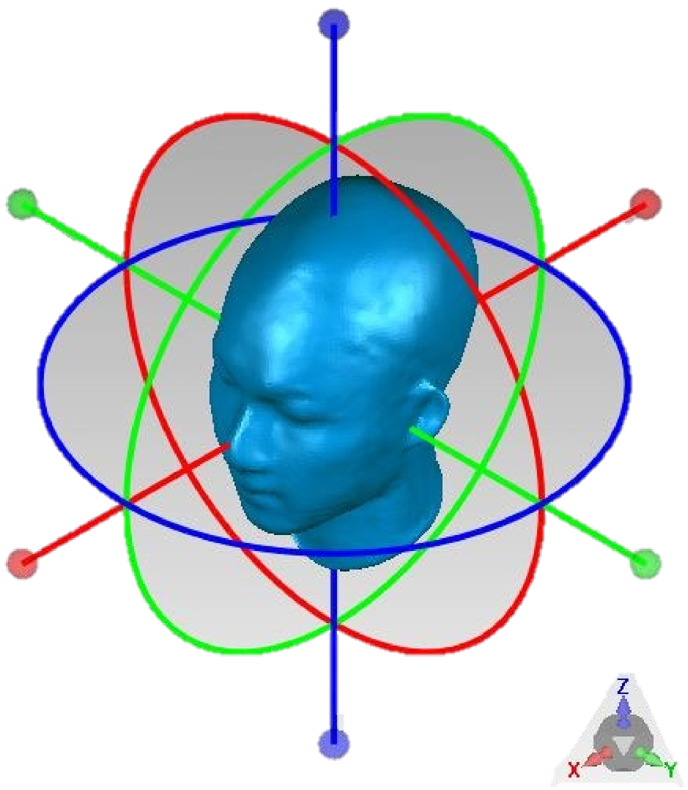

Fig. 3 *Head scan alignment*

Fig. 4 illustrates a set of essential head measurements for ensuring accurate helmet fitting, which plays a crucial role in comfort and safety. The measurements displayed include head length (HL) and the linear distance from the forehead to the back of the head, capturing the front-to-back dimension that influences how snugly a helmet fits along this axis. The bitragon width (BW) measures the widest horizontal span of the head across the temples, providing insight into the lateral width of the skull and helping to design helmets that accommodate the broadest points of the head. Head circumference (CF) is another critical measurement around the skull's most significant part. This measure is essential as it forms the primary parameter for helmet sizing, ensuring a wrap-around fit without excessive looseness or tightness. Arc length (AL) represents the curved distance from the forehead, over the top of the head, to the back, following the natural contour of the skull. This measurement is valuable for understanding the height and curvature of the head, allowing for helmet designs that conform more naturally to the head's shape. Face width (FW), another critical measurement, captures the width across the face, aiding in the design of helmets with adequate front openings to ensure comfort and unobstructed vision. Lastly, arc length head width (AW) provides a curved measurement across the side of the head, offering additional insight into the head's width and shape profile from a horizontal perspective.

To obtain these anthropometric measurements, a systematic 3D scanning process was used to capture detailed head data. To assess fit, participants' heads were scanned using advanced equipment capable of producing high-resolution digital models, both with and without helmets. The scans were conducted in a controlled environment to minimize errors and ensure uniformity in data collection. Measurements such as HL, BW, CF, AL, FW, and AW were extracted directly from these digital models, ensuring precision and consistency across the dataset. This method eliminated manual measurement errors and provided a more comprehensive understanding of the participants' head shapes. The data collected formed the basis for analyzing head dimensions and patterns, ultimately enabling the development of helmet designs optimized for safety and comfort.

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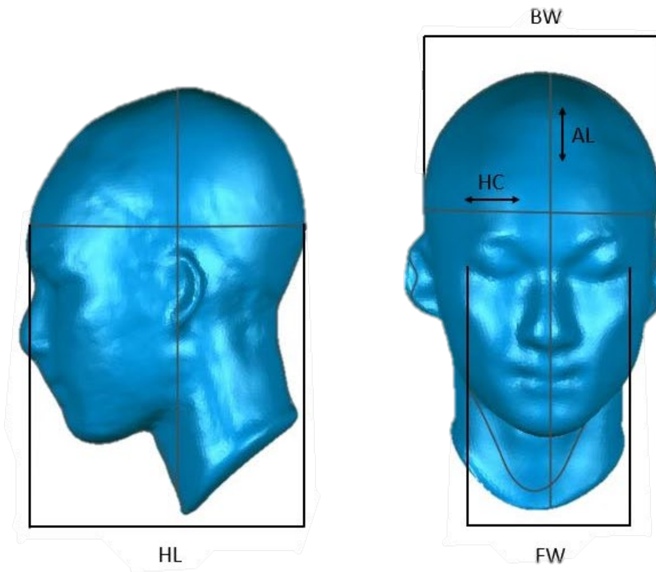

Fig. 4 *Head measurements*

Fig. 5 presents a 3D head model with clearly marked measurement points and orientation axes, providing a comprehensive view of essential head dimensions for helmet fitting. This figure displays various reference points and XYZ coordinates that define the head's position in space, ensuring measurements are consistent and accurate. Key measurements include head length (HL), which spans from the forehead to the back of the skull, capturing the head's depth, and arc length (AL), which follows a curved line from the forehead over the top to the back of the head, providing insights into the top contour and height needed for helmet design. Additionally, the model illustrates lateral dimensions, such as bitragion width (BW) across the cheekbones and face width (FW), showing the head's width at different planes. While head circumference (HC) is not shown as a single line, it is implied around the skull's widest point, indicating the overall size needed for a helmet’s secure fit. The 3D perspective in Fig. 5 allows for a thorough understanding of the head's shape, ensuring that helmets can be designed to fit comfortably, distribute weight effectively, and offer maximum safety with advanced 3D scanning methods for evaluating helmet fit.

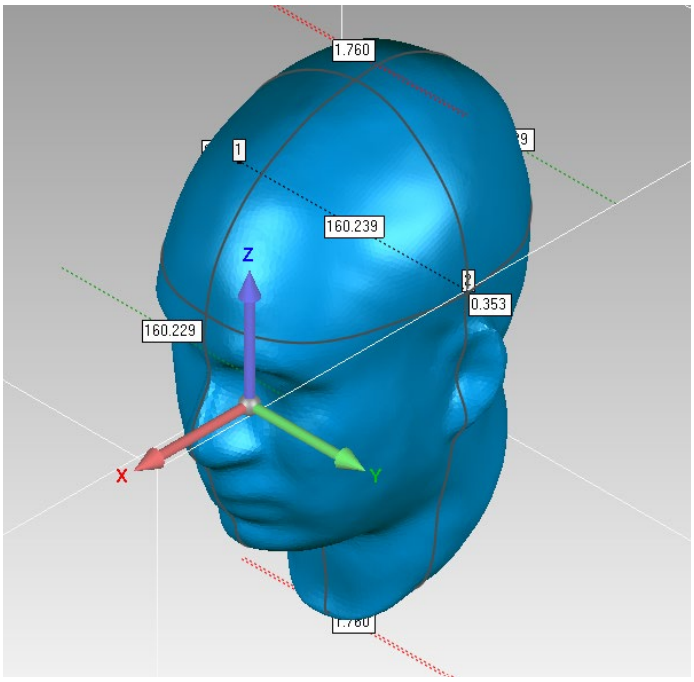

Fig. 5 *Measurement points and orientation axes of 3D head model*

3. Results

In interpreting the data analysis and results, it becomes apparent that a comprehensive understanding of these anthropometric variations requires a larger and more diverse sample size. The current dataset, while illuminating, may not capture the full spectrum of head sizes within the Malaysian population. Further research with an expanded cohort could provide more robust statistical analyses, including identifying trends and establishing standard deviation ranges for each measurement. This would allow researchers to assess whether the observed variations are statistically significant and indicative of distinct clusters of head sizes. All selected participants are over 18-30 years old, which suggests that they have reached their maximum adult growth and are suitable for the analysis. As shown in Table 1, various key head anthropometric measurements were taken, including Head Length (HL), Bitragion Width (BW), Head Circumference (HC), Arc Length (AL), Face Width (FW), and Arc Width (AW). The data show considerable variation among participants. For instance, there is a participant with a longer head length but shorter Bitragion Width, head width, and head height. Conversely, Participant 67, despite having the shortest head length, has a more extended Bitragion Width, Arc Length, and Arc Width, indicating a shorter head length but greater head height and width than others. Another example is Participant 27, who has the most extended head length and the second most comprehensive head among the five participants, resulting in the most significant head circumference. This variation in head anthropometric measurements suggests that a more extensive investigation with a larger sample size is needed to determine if a new cluster of head sizes is representative of the Malaysian population.

Ultimately, the implications of this study extend beyond mere measurements. Understanding head anthropometry can enhance various applications, including healthcare, where personalized medical devices and treatments can be developed based on specific anatomical characteristics. Additionally, this research could contribute to a deeper understanding of cultural and ethnic diversity in Malaysia, providing a framework for future studies that explore the interplay between physical attributes and societal factors. Overall, a detailed examination of anthropometric data is crucial for fostering a comprehensive understanding of human diversity, guiding practical applications, and addressing public health needs within the Malaysian context. Fig. 6 depicts the measurement of anthropometry data, focusing on critical points of the human head.

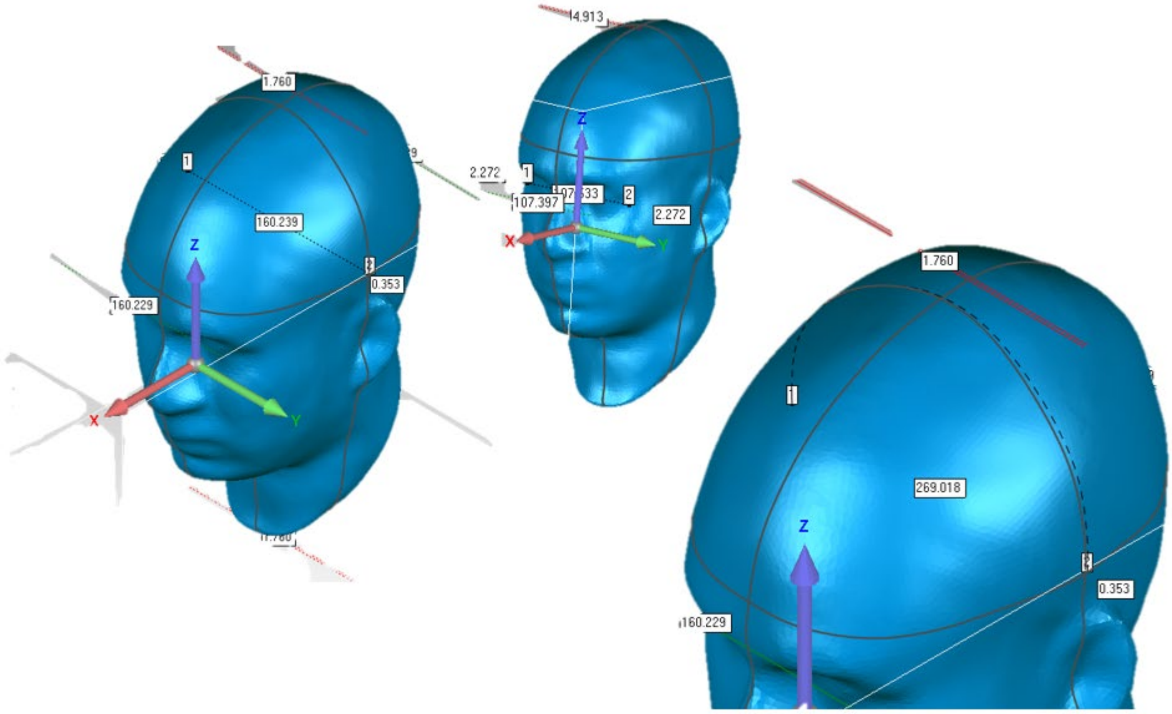

Fig. 6 *Measurement of anthropometry data*

The image presents multiple 3D views of random participants' head models, indicating how various anthropometric dimensions are measured. Specific landmarks on the head, such as the forehead, sides, and top, are marked with measurement axes (X, Y, Z) to accurately capture dimensions like head length, breadth, and height. These measurements are crucial for assessing head size and shape, which is essential in helmet design and fit assessment. The detailed visualization allows for a clearer understanding of the relationship between different head dimensions and emphasizes participant variability. By capturing the three-dimensional structure of each head model, the figure facilitates a nuanced analysis of how individual anthropometric traits influence overall head geometry. This is particularly important in ergonomic studies, where understanding the nuances of head shape can directly impact product design and user comfort. In the context of helmet design, the data presented in this figure serve several critical functions. First, by identifying specific anatomical landmarks, designers can ensure that helmets conform closely to the natural contours of the head, enhancing both comfort and safety. Proper fit is vital in mitigating the risk of injury during impacts; poorly fitting helmets can compromise protection and increase the likelihood of head injuries.

Table 1 *Anthropometry measurement of 1-100 participants*

Measurements	Head length (HL)	Bitragion width (BW)	Head circumference (HC)	Face width (FW)	Arc length head width (AW)	Arc length (AL)
Highest (P-27)	226.19	189.62	632.54	126.91	331.59	357.44
Lowest (P-67)	180.51	157.95	536.61	100.12	255.28	257.42
Average	198.89	170.38	582.21	112.53	290.39	308.33
Standard deviation	8.42	5.66	18.43	5.55	16.47	16.67

The dataset reveals a significant range and variability in head dimensions, in which the highest participant (participant 27) has large measurements, including a head length of 226.19 mm, Bitragion Width of 175.64 mm, head circumference of 632.54 mm, face width of 126.91 mm, arc length head width of 331.59 mm, and arc length of 357.44 mm. In contrast, the lowest participant (participant 67) has much smaller measurements, with a head length of 180.51 mm, Bitragion Width of 157.95 mm, head circumference of 536.61 mm, face width of 100.12 mm, arc length head width of 255.28 mm, and arc length of 257.42 mm. The average measurements, including a head length of 198.89 mm, Bitragion width of 170.38 mm, head circumference of 582.21 mm, face width of 112.53 mm, arc length head width of 290.39 mm, and arc length of 308.33 mm, provide a baseline for designing helmets that can adapt to various head sizes. The standard deviations for each measurement, ranging from 5.55 mm for face width to 18.43 mm for head circumference, highlight the variation in each dimension, emphasizing the need for helmets to accommodate various head sizes and shapes. The data underscores the importance of designing helmets with flexible materials, padding, and designs to cater to various head shapes and sizes, ensuring maximum protection and user satisfaction. The anthropometric study reveals significant individual variability of helmets that accommodate a wide range of head sizes and shapes for optimal protection and comfort. Participants with larger head dimensions require helmets with larger, elongated interior spaces and adjustable fitting systems. In comparison, those with smaller head dimensions need helmets with compact designs, additional padding, and secure fit mechanisms. By accommodating variations in bitragion width, face width, arc length, head width, and arc length, helmets can be designed to provide a secure fit for all individuals, enhancing safety and satisfaction for all users.

Fig. 7 illustrates a cross-sectional comparison between the highest and lowest head shapes. The diagram features two outlines: one marked in yellow, representing the Highest head shape, and the other in blue, representing the Lowest head shape. The comparison visually analyzes the variations in head shape dimensions within a specific population. The coordinate system shown (with X, Y, and Z axes) may indicate the orientation or reference plane used for the cross-section.

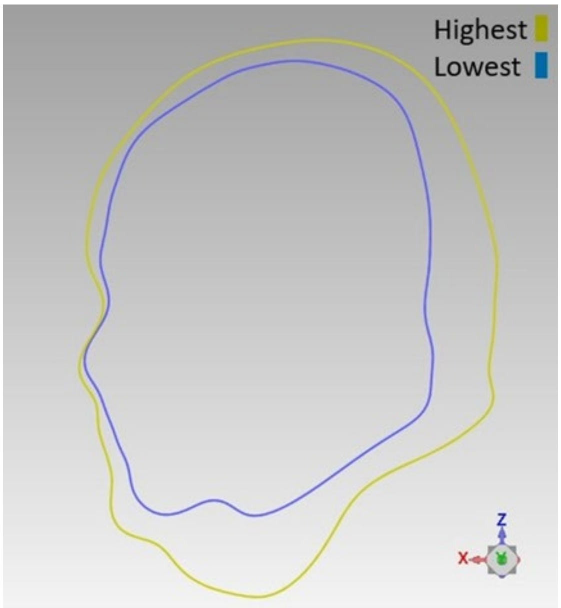

Fig. 7 *Cross-sectional comparison between highest and lowest head shapes*

Then, Fig. 8 presents a comparison of software-generated 3D graphics between the highest (L) and lowest (R) head shapes obtained from anthropometric measurements. The images highlight the variations in cranial shape and size, clearly representing the differences in head morphology across the sampled data. The comparison allows for an in-depth analysis of the disparities in head dimensions, which is significant in applications such as designing helmets, headgear, and other equipment that must fit the human head properly. The left model, representing the Highest head shape, appears broader and more significant compared to the Lowest head shape on the right, which is more compact. This indicates potential areas where standard headgear designs might need adjustments to accommodate diverse head shapes, ensuring comfort and safety for users.

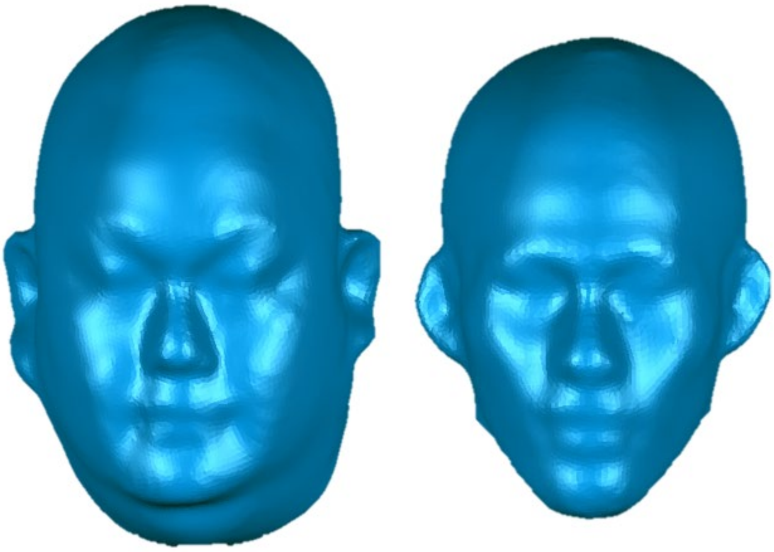

Fig. 8 *The comparison of software graphics between the highest (L) and the lowest (R) head shape of anthropometry measurement*

4. Discussion

In the previous study by Ellena et al., 2017, the comparison between these two studies reveals shared approaches and distinct differences in their methodologies and outcomes. Both studies utilize 3D scanning technology to capture detailed head shapes, focusing on improving headgear design. Both align and standardize the scanned data, emphasizing the importance of accurate head shape representation. However, the studies diverge in their techniques and scope. The Australian study incorporates a modified hierarchical clustering algorithm to group head shapes and generate new headform models, highlighting significant differences from existing standards and suggesting the need for revised headgear design standards. In contrast, while recognizing the variability in head dimensions, the Malaysian study focuses on creating a comprehensive database for helmet design without challenging current standards. The sample sizes and demographics also differ, with the Australian study involving a broader and larger sample, which may impact the generalizability of its findings. Despite these differences, both studies underscore the variability in head shapes within their respective populations and the importance of tailored design in enhancing the fit and safety of headgear. For others, the comparison between both studies reveals shared and distinct approaches in using 3D anthropometric data for helmet design. Both studies employ 3D scanning technology to capture and analyze head measurements, emphasizing the importance of accurate data collection and alignment for assessing helmet fit.

The anthropometric studies present varying methodologies and outcomes tailored to distinct population groups and application purposes. The study by [19] primarily aims to capture head and face data using traditional measurement tools (tape and calipers) and high-resolution 3D scanners across multiple regions in China. With a sample size of 2,200 participants, the study gathers detailed measurements intended to improve product ergonomics, particularly for designing region-specific headgear such as VR/AR headsets and safety glasses. By providing comprehensive 3D data, this study highlights the advantages of 3D imaging in capturing the unique contours of the human head for practical applications in product design. In contrast, the study by [20] focuses on children aged 6 months to 7 years to address fit issues in pediatric ventilation masks. This study uses both traditional measurements and 3D scanning (utilizing the 3dMD Face system), ensuring accuracy through comparison. Its findings underscore the necessity of age-appropriate designs to ensure comfort and safety. It compares Dutch children's dimensions with prior Dutch and North American datasets to reveal significant anthropometric differences that impact device fit.

Meanwhile, this main study explores helmet fittings explicitly tailored to Malaysian users. Using 3D scanning and the (HFI) as a standard metric employs clustering to create helmet sizes that accommodate local head shapes, ensuring optimal fit and safety for Malaysian workers in various industries. By grouping helmet sizes according to specific population characteristics, this research emphasizes the importance of customizing headgear to the demographic it serves, thus enhancing comfort and protection. While all studies utilize 3D scanning technologies, their focus diverges: the Chinese study targets ergonomic design for general wearables, the Dutch study centers on pediatric medical equipment, and this research prioritizes helmet safety in industry-specific applications for Malaysian users. Each study's methodology reflects these differing goals, adapting 3D anthropometric measurements and traditional methods to suit their respective populations and design requirements best. The given anthropometric data offers crucial insights for designing safety helmets with diverse head sizes and shapes. Analyzing the distribution, range, and correlation between measurements like Head Length, Bitragion Width, Head Circumference, Face Width, and Arc Length reveals the variability within the population, underscoring the need for adaptable helmet designs. Considering demographic factors such as gender, age, and regional variations can further refine the fit and comfort of helmets. This data also supports the development of customizable helmets using advanced technologies like 3D scanning, ensuring a precise fit for individual users. By aligning with safety standards and focusing on ergonomics, the study highlights the importance of creating helmets that provide maximum protection and enhance user comfort and satisfaction, paving the way for future research and innovation in helmet design.

5. Conclusion

In conclusion, applying 3D scanning technology combined with anthropometric analysis offers significant advancements in helmet design, particularly in optimizing fit and enhancing safety for Malaysian users. By acknowledging the diverse head shape and size variations within this population, this methodology effectively addresses the inadequacies of conventional sizing systems, often based on generalized data from Western populations. These traditional sizing systems frequently lead to discomfort, instability, and reduced safety, which can negatively impact the consistent use of helmets. Incorporating clustering algorithms to classify head shapes further enriches this approach, enabling the development of a more precise, user-focused helmet-sizing system. This refined system improves the stability, comfort, and overall user experience, making helmets more accessible and appealing for regular use. Moreover, employing the Helmet Fit Index (HFI) as a quantitative measure ensures that helmet designs maintain uniformity in fit and quality across various head types, fostering higher safety standards.

This study highlights the critical role of leveraging regional anthropometric data in enhancing helmet design and manufacturing. By aligning helmet dimensions with actual head measurements, manufacturers can produce helmets that provide better coverage and protection, reducing the likelihood of head injuries. The research findings encourage the integration of advanced technologies such as 3D scanning and algorithmic clustering in personal protective equipment. Such advancements have the potential to reshape industry practices, setting new benchmarks for comfort and safety in helmet design. Future studies should explore the scalability of these methods to other types of headgear and protective equipment, broadening the scope of application. Additionally, further investigation into the long-term user feedback and field testing will solidify the effectiveness of these sizing systems in real-world scenarios. Ultimately, this approach paves the way for more inclusive, data-driven design practices that cater to the unique needs of diverse global populations, ensuring better compliance, safety, and overall satisfaction.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the paper's publication.

Author Contribution

The authors confirm contribution to the paper as follows: ***Study conception and design:*** *Syahrizan Azlan, Helmy Mustafa El Bakri, Salwa Mahmood;* ***Data collection:*** *Syahrizan Azlan;* ***Analysis and interpretation of results:*** *Syahrizan Azlan, Helmy Mustafa El Bakri, Salwa Mahmood;* ***Draft manuscript preparation:*** *Syahrizan Azlan, Helmy Mustafa El Bakri,* Salwa Mahmood, *Nur Fitrah Najiha Muhamad Dzahir. Machimontorn Promtong, All authors reviewed the results and approved the final version of the manuscript.*

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