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RESEARCH ARTICLE

The Effect of Motorcycle Helmet Type on Head Response in Oblique Impact

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ABSTRACT - In Malaysia, riding motorcycles is a popular mode of transportation, particularly in urban areas where traffic congestion is prevalent. Additionally, motorcycles are relatively affordable and have low fuel consumption, which makes them an attractive option for many. Per Malaysian traffic laws, riders must wear helmets while riding. As a result, various brands and types of helmets are available for purchase. However, with the increasing popularity of online shopping platforms, many individuals opt to purchase helmets online despite the uncertain quality control of these products. This study aims to assess the effectiveness of three different types of motorcycle helmets in protecting the head from injury. The helmet types evaluated in this unbiased study include full-face, open-face, and half-coverage helmets. The head injury predictors used in this study include Peak Linear Acceleration (PLA), Peak Rotational Acceleration (PRA), Head Injury Criterion (HIC), and Brain Injury Criterion (BrIC). Each helmet was subjected to an impact in a controlled environment using a 6-kg cylinder attached to a pendulum arm, with the impact directed at the front of the helmet at a speed of approximately 6 m/s. Full-face and open-face helmets performed exceptionally well in terms of linear parameters (PLA and HIC). The PLA and HIC of half-coverage helmets are nearly 70% and 50% higher than full-face and open-face helmets. All helmets perform poorly against rotational impact (PRA and BrIC). This shows that helmet design needs to be improved to enhance protection against rotational impact. This study represents the first case study in Malaysia to gather mechanical head injury data comparing the protective performance of different helmet types under both linear and rotational impact. These findings may provide a more accurate understanding of helmet performance in protecting against head injuries.

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1.0 INTRODUCTION

There remains a significant disparity in the rate of road death between high-income countries and middle to low-income countries, according to data from the World Health Organization (WHO). High-income countries such as the United States of America (USA) and Europe have successfully reduced the rate of road death to 15.6 and 9.3 deaths per 100,000 population, respectively. In contrast, Africa and Southeast Asia struggle with high road death rates, currently at 26.6 and 20.7 deaths per 100,000 people, respectively [1]. The authors of this study concur with the statement made by Zainal Abidin and colleagues that Malaysia and other countries worldwide also face the same issue of rising road deaths [2]. Figure 1 illustrates a sudden rise in annual road deaths in Malaysia between 1992 and 1996, after which the statistics fluctuated above 6,000 people until recent years. Policy-makers in the country are actively developing solutions to address this issue and reduce road deaths.

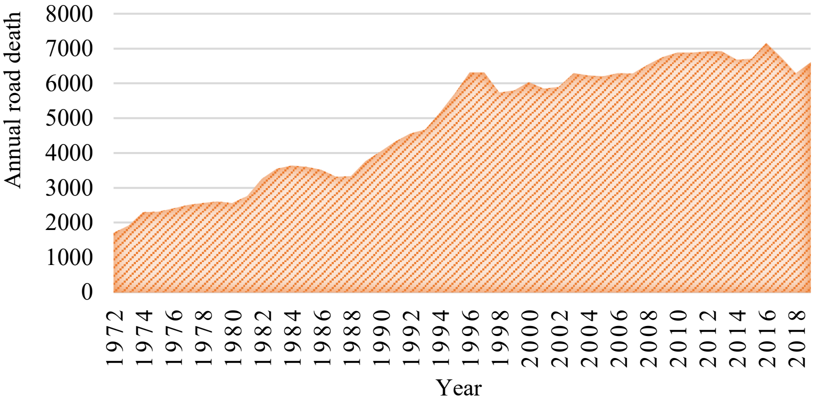

Figure 1. Total road deaths in Malaysia from 1972 until 2018

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One possibility for reducing road deaths is that the government has implemented stricter traffic laws and regulations. The constant road safety interventions organised by the government may have slowly contributed to the decrease in the road death index. These interventions include the Safety Helmet Rules in 1973, Seat Belt Rules in 1978, Road Transport Act 1987 for Drunken Driving Speed, Speed Limit Rules in 1989, Motorcycle Daytime Running Headlight Regulation in 1992, Road Safety Programmes in 1997, Integrated Road Safety Operations (*Ops Sikap*) since 2001, and many road safety plans. Statistical analysis has been used to predict future road traffic accidents, with the aim to halve its number in accordance with the sustainable development goal (SDG) 3.6 [3]–[5]. More recently, machine learning algorithms, such as Artificial Neural Networks and Support Vector Machines, have been used in many sectors to predict the outcome of an action [6]–[10], including road traffic accidents [11]–[13].

1.1 Motorcycle Road Death in Malaysia

Motorcycles are primarily used for leisure in high-income countries such as the USA and Europe, whereas in Malaysia, standard or scooter-type motorcycles are a common choice. The population of Malaysia has developed a preference for low-engine capacity motorcycles due to their affordability and low fuel consumption. Furthermore, motorcycles are optimal for traffic congestion, particularly in big cities. This trend resembles other heavily populated Southeast Asian nations such as Thailand, Vietnam, Indonesia, and the Philippines. The rise of motorcycles on the roads of Malaysia has preceded a dominant representation of motorcycle accidents in the nation's traffic fatality data, accounting for more than half of all road deaths each year [14]–[17]. The issue of motorcycling in Malaysia is distinctive with the term "Mat Rempit" or daredevil riders. These daredevil riders are often involved in illegal street racing and dangerous riding stunts. Most daredevil riders in Malaysia are young Malay males, some as young as 12 [18]–[20]. Furthermore, these riders are believed to possess only learner driving licenses or no licenses [21].

1.2 Traumatic Brain Injury

The Safety Helmet Rules that were enacted in 1973 obligated Malaysian riders to wear motorcycle helmets as protective equipment to avoid head injury occurrences, which mostly lead to Traumatic Brain Injury (TBI) [5], [22], [23]. TBI is a severe public health concern, with high death rates reported in the United States. Unfortunately, there has been a lack of published TBI statistics for Malaysia in recent years. The National Trauma Database, Malaysia (NTrD), has not yet released any data on TBI cases. However, in 2011, NTrD published major trauma statistics based on data collected from January to December 2009 in eight emergency and trauma departments in hospitals across Malaysia. During that year, there were 166,786 admissions to emergency and trauma departments. 78.35% of the 4,453 primary trauma patients had head and neck injuries with an Abbreviated Injury Score (AIS) ≥ 3, which indicates a serious, severe, critical, or maximal injury. Road traffic injuries contributed to nearly 80% of Malaysia's trauma cases in 2009, with most cases occurring in males aged 15 to 24 [24], [25]. Motorcyclists and their passengers had the highest statistics, accounting for 72.36% of all road traffic injuries.

An observational study conducted in 2011–2015 found that 90% of the study population wore helmets, yet head injury remained a significant factor in fatalities [16]; therefore, the effectiveness of motorcycle helmets in preventing head injuries has been debated worldwide. Full-face helmets are the most effective in reducing the risk of head injury [26]–[28]. A retrospective study in a small town in Korea concluded that full-face helmet has the lowest injury severity score among other types of helmet. Another retrospective study in California concluded head and neck injury of the full-face helmet wearer has the lowest percentages as compared to open-face and half-coverage helmets. However, some studies have found no significant difference between full-face helmets and other types of helmets except for improper helmet usage [29]–[32]. However, universal helmet laws have been shown to reduce head injuries in some countries [33], [34], contradicting the Malaysian case scenario when the universal helmet law was first introduced, where the rate of motorcyclist fatality spiked [5]. The lack of public awareness and law enforcement at the time may have contributed to the lack of compliance with the law.

1.3 International Certification of Motorcycle Helmet

Motorcycle helmets must meet international safety standards to ensure their quality and effectiveness in protecting riders. These standards are set by codes such as FMVSS No. 218, Snell M2015/M2020, BS 6658, ECE 22.05, and JIS T 8133: 2000. International certification organisation bodies mandate that helmets must undergo impact testing at specific speeds. For example, FMVSS No. 218 requires impact testing at speeds of 5.2 m/s and 6.0 m/s, while BS 6658 requires testing at speeds ranging from 4.6 to 7.5 m/s. UNR 22.05, Snell M2000, and M2005 standards may test at a speed of 6.6 to 7.8 m/s. In addition to these international standards, the Road Transport Department (RTD) of Malaysia has regulations that require all helmets sold in the country to meet the safety standards MS 1 adopted from the UNR 22.05, which includes the resistance to penetration test and an impact absorption test.

In Malaysia, the quality and safety of motorcycle helmets are evaluated by the Department of Standards Malaysia (STANDARDS MALAYSIA) and the Standard and Industrial Research Institute of Malaysia (SIRIM Berhad) through a series of tests. These tests include a penetration resistance test and an impact absorption test. The penetration resistance test requires a 4.5 kg steel striker to be dropped onto the helmet from a height of 2,000 mm. Meanwhile, the helmet is dropped from a height of 2,150 mm onto a flat anvil in an impact absorption test. The helmet's ability to absorb impact is measured using linear accelerometer cables [35]. To be certified and legally sold in Malaysia, helmets must not exceed 275 g Peak Linear Acceleration (PLA) and 2,400 Head Injury Criterion (HIC) score. It's worth mentioning that, as Meng observed, head injuries sustained during road accidents may also be caused by rotational acceleration, such as subdural hematomas or diffuse brain injuries. Rotational acceleration is considered to be more dangerous than linear acceleration [36]. The current certification test does not take into account rotational acceleration [37]–[39]; hence, there's a need for further research to understand the association between rotational motion and TBI [40].

Despite these regulations by international organisations, there is a growing concern over the availability of non-certified motorcycle helmets, mainly imported from China and sold online. These helmets are either non-certified by international standards or need proper safety precautions, such as half-coverage helmets. Non-certified helmet usage is prevalent among occupational riders in Malaysia, according to studies by Kulanthayan et al. (2012) and Yellappan et al. (2019) [41], [42]. As such, it is crucial to assess the protective performance of motorcycle helmets better to understand the association between helmet use and head injury. Thus, the primary goal of this study was to study the protective performance of full-face helmets, open-face helmets, and half-coverage helmets.

2.0 METHODOLOGY

2.1 Experiment Equipment and Devices

Head impact analysis is normally performed using a commercialised monorail impact test. However, purchasing a commercialised high-impact testing machine is not a viable option for this study due to its high cost. Hence, a customised pendulum impact test rig was developed to bring the same purpose as the head impact experiment. The pendulum impact test rig is emulating Thorne and colleagues' method of striking the NOCSAE head form [43]. The rig measured 2.00×0.62×2.06 m, as shown in Figure 2.

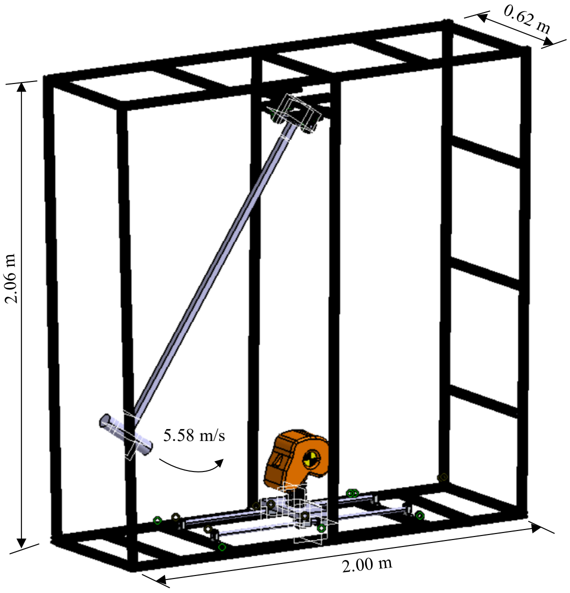


Figure 2. Dimension of the pendulum test rig

A 1.50 m pendulum arm was attached to the middle of the test rig. It was designed in a pendulum style to enable easy repetition of impacts. The pendulum arm could be released from a maximum of 90° to lower angles depending on the approximate desired velocity. The impact in this research was conducted at the lowest point of gravity to maximise the possible speed. The average recorded speed was 5.58 ± 0.29 m/s (measured using the SpeedClock app for iOS, which records the footage at 240 frames per second). Motorcycle helmet testing worldwide is conducted at speeds ranging from 3.05 to 10.0 m/s [44]–[50]. Thus, the research in this study selected a speed within that range, which is nearly 6.0 m/s.

The materials used in the rig's construction were chosen based on their availability in the research lab, with a focus on aluminium profiles for their strength and durability. Aluminum is a lightweight yet robust material that has excellent mechanical properties. This makes it ideal for use in applications where high strength-to-weight ratios are essential. Additionally, aluminium is corrosion-resistant, non-magnetic, and has good thermal conductivity, all desirable characteristics for a test rig. Furthermore, aluminium profiles can be easily machined and assembled, thus making them a convenient and practical material choice for constructing customised test rigs.

To simulate the impact absorption that may occur to a human in a road traffic accident, researchers in this study utilised an Anthropomorphic Test Device (ATD) or a crash test dummy. Another test platform made of aluminium profiles was placed on the ground to mount the ATD, as shown in Figure 3. The ATD used in this research was a Hybrid III head and neck dummy developed by Humanetics. The ATD dummy is widely acknowledged and used in many automotive testing and road safety applications. It is designed to be biofidelic, meaning it has size, weight, stiffness, and impact absorption characteristics that mimic an actual human. ATDs are generally classified by age, impact direction, size, and sex. The Hybrid III head and neck are composed of cast aluminium parts that weigh 6.08 kg, and the skin is made of removable vinyl. The neck is made of segmented rubber and aluminium, and it can simulate rotational, flexion, and extension responses to impact testing.

Figure 3. The hybrid III head and neck dummy

A Shimmer 200g Inertial Measurement Unit (IMU) sensor was placed inside the Hybrid III dummy's skull at the head's centre of gravity to collect data on linear and rotational velocities during the crash impact experiment. Figure 4 shows the sensor equipped with three accelerometers and a gyroscope. The data was transmitted directly from the Shimmer to a laptop through Bluetooth and recorded in real-time using ConsensysPro software version 1.6.0.

(a) (b)

Figure 4. The Shimmer 200g Inertial Measurement Unit (IMU)

The raw data on linear velocities were uncalibrated and needed to be processed using MATLAB® 2016b software to produce calibrated data, which generate linear accelerations in the *x, y*, and *z* axes every 0.001 seconds. On the other hand, the raw data on rotational velocities could be easily converted into a .csv format and viewed on Microsoft Excel for further analysis using ConsensysPro. The calibrated data on the linear and rotational motion was prepared for further processing and viewed as a line graph in Microsoft Excel to shorten the data at the area of impact for easier management.

The gyroscope in the sensor was able to measure rotational velocities in the three axes of *x, y,* and *z.* The rotational motion data in all three axes underwent numerical differentiation once to obtain rotational velocities. Still, this data needed to be filtered using a fourth-order Butterworth filter with a cut-off frequency of 167 Hz to eliminate error accumulation. This process could be achieved by installing a Microsoft Excel add-in. The resulting linear acceleration was calculated from the data in the *x, y,* and *z* axes. In contrast, the highest value of rotational velocities in the *x, y,* and *z* axes was determined for the rotational motion output calculation.

2.2 Experimental Procedure

In the crash impact experiment, three categories of motorcycle helmets were employed, as detailed in Table 1. The full-face, open-face, and half-coverage helmets had 3, 5, and 6 counts, respectively, and the average experimental results were recorded for each helmet type. The impact location was fixed at frontal impact only because head-on collisions are the most common type of accident for motorcycles and other vehicles in interactions involving two or more vehicles and motorcycles. Therefore, the helmet's frontal location is considered the most common location for rider head injuries. Figure 5 illustrates the design of three different motorcycle helmet types used in the experimental procedure. Several helmet brands were purchased and considered for each type in the experiment. Nevertheless, conducting tests without disclosing the helmet's brand name is standard practice to ensure unbiased and objective testing. The purpose of impact testing is to evaluate the helmet's performance in protecting the wearer's head from injury during an impact without any preconceptions or preferences based on the brand name; thus, the motorcycle helmet brand is typically not disclosed to prevent any potential bias or influence on the test results. If the helmet brand were disclosed, the test results could be influenced by factors such as brand reputation, previous experience with the brand, or even personal biases. This helps maintain the integrity and credibility of the testing process and the results obtained, ultimately leading to improved helmet safety standards and better protection for motorcyclists.

Table 1. Details of each motorcycle helmet

No.	Type of motorcycle helmet	Count	Average weight (g)	Certification
1.	Full-face helmet	Three helmets	1,559	Certified by SIRIM MS 1
2.	Open face helmet	Five helmets	1,258	
3.	Half coverage helmet	Six helmets	651	Non-certified


(a) full-face helmet (b) open-face helmet (c) half-coverage helmet

Figure 5. Different types of helmet design

Both full-face and open-face helmets used in the experiment are SIRIM MS 1 certified, with the full-face helmet regarded as the safest motorcycle helmet due to its characteristics covering the entire head and having a hard shell-supported chin bar near the mouth area. Meanwhile, the open-face helmet type is commonly used by motorcyclists in Malaysia due to its affordable price, yet it is SIRIM certified. The half-coverage helmet used in the experiment has no certification approval and is the lightest among the helmets. This suggests that more materials as well as accessories were included in both helmets, especially the full-face helmet.

The experiment also involved testing an unhelmeted ATD as a control or baseline condition. This allows researchers to compare the effects of different helmets with the impact on an unprotected head. By having a reference point without any protection, they can determine the extent to which each type of helmet reduces the risk of injury compared to not wearing any helmet. The pendulum arm was released such that it impacted the forehead of ATD. Figure 6 shows photographs of before, upon, and after the helmet impact. A nylon cap was positioned to cover the top of the cylinder to prevent it from unintentionally damaging the ATD's skin. This action was only performed once at the frontal location of the helmet to prevent data inconsistency due to the degradation of helmet performance. It is important to note that each helmet was firmly buckled to ensure the impact was secured at the helmet's hard-shell body and not on the visor. The neck of the Hybrid III was not locked to the test platform to simulate the idea that the human neck may not be strengthened during an impact. Therefore, the Hybrid III slides after being impacted by the pendulum weight, as victims in any accident may not expect the incoming hit. However, this may differ for head impact experimental procedures in sports such as soccer heading, where players may intentionally strengthen their necks before commencing soccer heading.


Figure 6. Sequence of pendulum impact when the pendulum cylinder struck the open-face helmet

2.3 Head Injury Predictors

In the field of traumatic brain injury research, various parameters have been identified that can be used to predict head injuries. These include peak linear acceleration (PLA), peak rotational acceleration (PRA), head injury criterion (HIC), and brain injury criterion (BrIC). In this study, we focused on evaluating the protective performance of helmets using these indicators. Initially, data were extracted for PLA and PRA, representing the maximum linear and rotational acceleration values, respectively, as calculated using Equation 1. PLA and PRA are the maximum linear and rotational acceleration value measured during an impact event. Linear acceleration and rotational acceleration are the rate of change of an object's velocity in a straight line and an object's rotational velocity upon impact. PLA is commonly used in helmet standards to evaluate the protective performance of helmets, whereas, on the other hand, PRA is a relatively new indicator that is receiving increasing attention in helmet testing.

$$|R| = \sqrt{x^2 + y^2 + z^2} \tag{1}$$

where $|R|$ is resultant acceleration, x is acceleration in the *x*-direction, y is acceleration in the *y*-direction, and z is acceleration in the *z*-direction.

The HIC in Eq. (2) is a measure of the severity of a head injury that results from an impact. It is a value calculated from the linear acceleration data, including the PLA. It is intended to estimate the risk of head injury based on the PLA and the impact duration. The impact duration used for calculating the HIC is typically within a range of 10 to 20 milliseconds. The exact duration used for the HIC calculation can vary depending on the specific helmet standard. The duration of 0.015 seconds is commonly used in several helmet standards, such as the Snell Memorial Foundation and FMVSS218 in the USA. This duration is chosen based on the research showing that most injury-causing events occur within this time frame.

$$HIC = \left\{(t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\}max \tag{2}$$

where HIC represents the Head Injury Criterion, t_1 is the initial time when HIC is calculated, t_2 is the final time when HIC is calculated, and $a(t)dt$ is linear acceleration. The HIC is a widely accepted standard for evaluating the protective performance of helmets and is used in many international helmet standards. The HIC is calculated by integrating the acceleration over a certain period, including the PLA. The resulting area under the curve (AUC) is then multiplied by a weighting factor that considers the impact's duration, and this product is the HIC score. The HIC score is a relative measure of head injury risk. A higher score means a higher risk of injury and vice versa.

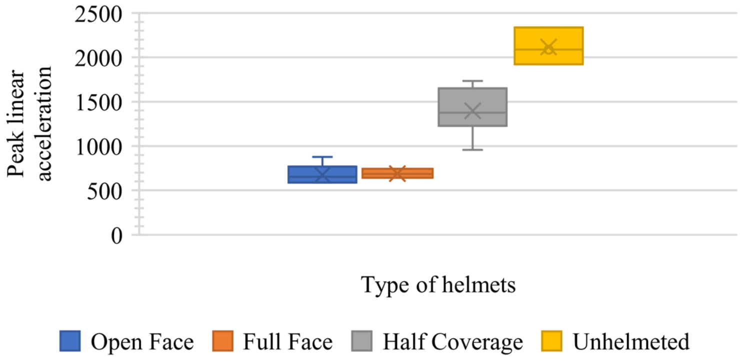
In addition to linear motion, this research also focused on rotational motion and using the BrIC to predict head injuries. The BrIC is a measure of the severity of a brain injury that results from an impact. It is similar to the HIC in that it is calculated from the acceleration data. Still, instead of linear acceleration, it is based on rotational acceleration. The BrIC is intended to estimate the risk of brain injury based on the peak rotational acceleration and the impact duration. The BrIC is calculated by taking the maximum value of the rotational acceleration over three perpendicular axes (*x, y, z*), as shown in Eq. (3) [51]. The BrIC score is also a relative measure of injury risk, with a higher score indicating a higher risk of injury. The BrIC is a relatively new indicator receiving increasing attention in helmet testing [51]–[53]. It is not yet widely used in international helmet standards. However, some studies have found that the BrIC provides a more accurate measure of the risk of brain injury than the HIC. It has been proposed as a potential replacement or addition to HIC in future helmet standards. The BrIC was calculated using the formula in Eq. (3), which takes into account rotational velocity in the direction of the -*x*, -*y*, and -*z*-axis, measured in rad/s, and critical rotational velocities provided by Takhounts et al. [51].

$$BrIC = \sqrt{\left(\frac{max(|\omega_x|)}{\omega_{xC}}\right)^2 + \left(\frac{max(|\omega_y|)}{\omega_{yC}}\right)^2 + \left(\frac{max(|\omega_z|)}{\omega_{zC}}\right)^2} \tag{3}$$

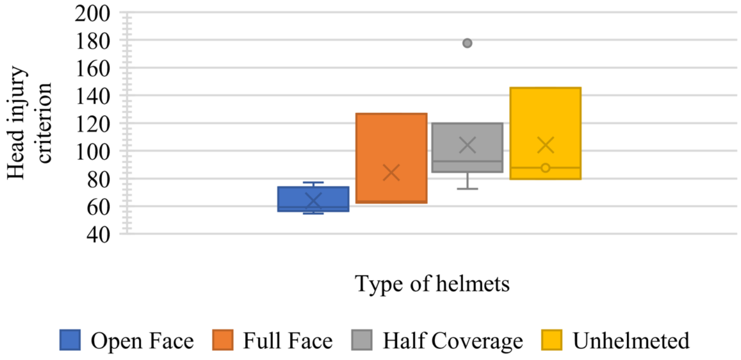
where $BrIC$ represents Brain Injury Criterion, ω_x is the angular velocity in *x*-direction, ω_{xC} is the critical angular velocity in *x*-direction (66.25), ω_y is the angular velocity in *y*-direction, ω_{yC} is the critical angular velocity in *y*-direction (56.45), ω_z is the angular velocity in *z*-direction, and ω_{zC} is the critical angular velocity in *z*-direction (42.87).

3.0 RESULTS AND DISCUSSION

This study aims to evaluate the effectiveness of three distinct types of motorcycle helmets in protecting the head from injury. It is worth noting that the current international standard certification for helmets only requires manufacturers to meet criteria for head injury predictors at linear acceleration. The results of this controlled environment experiment indicate that both full-face and open-face helmets exhibit superior protection in terms of peak linear acceleration (PLA), as depicted in Figure 7(a). Furthermore, our findings align with those other researchers who have found no significant difference in head injury severity between full-face and open-face helmets, provided they are appropriately worn [29], [30], [32]. However, it should be noted that a case study conducted by Tsai, Sung, Erhardt, and colleagues concluded that full-face helmets are the best option for reducing the risk of head injury based on data collected in Taiwan, Korea, and California [26]–[28]. Nevertheless, this study is observational, whereas ours provides mechanical data. It is worth noting that the open-face and full-face helmets have lower HIC than half coverage and unhelmeted impact. Both half coverage and unhelmeted impact have similar HIC averages. Overall, the risk of head injury due to linear motion is lower if certified open-face and full-face helmets are used. The risk could be further reduced by incorporating additional padding within the helmet.



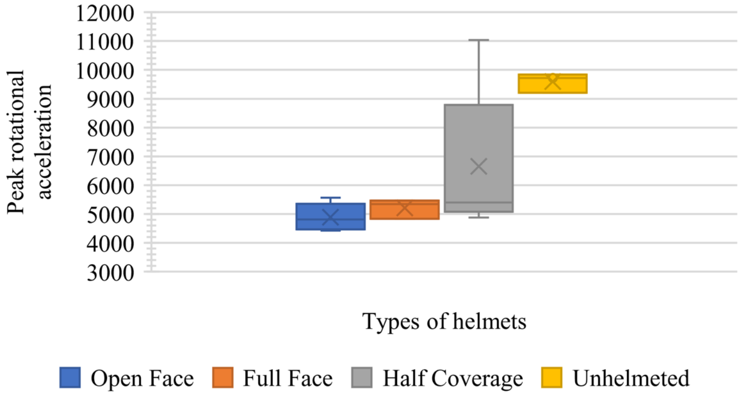
(a)



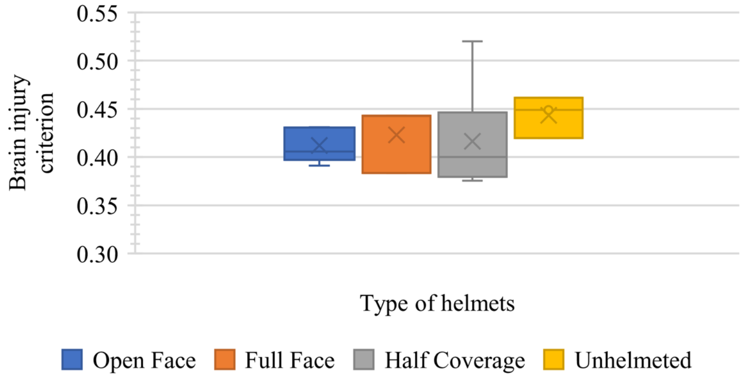
(b)

Figure 7. Boxplot display of (a) peak linear acceleration (b) head injury criterion

The study then explores further the evaluation of PRA and BrIC scores. Figure 8(a) presented both open-face and full-face helmets, again suggesting giving the best protection towards rotational motion, PRA injury predictor. Interestingly, Figure 8(b) illustrates that all helmet types and unhelmeted impacts have quite a similar BrIC average. This is true, indicating all helmet type used in the experiment was not featured with technology to overcome rotational injury. It is essential to note that the full-face, open-face, and half-coverage helmets used in this study are conventional helmets that are commonly available in the market. They are manufactured to meet the current certification standards, focusing only on linear motion impact. However, rotational motion is different as the head can be rotated, for example, at 25 rad/s, even while wearing a conventional helmet. Therefore, the risk of injury due to rotational motion may still occur even with additional padding. Previous research has agreed that the friction coefficient significantly influences rotational acceleration [54], [55].



(a)



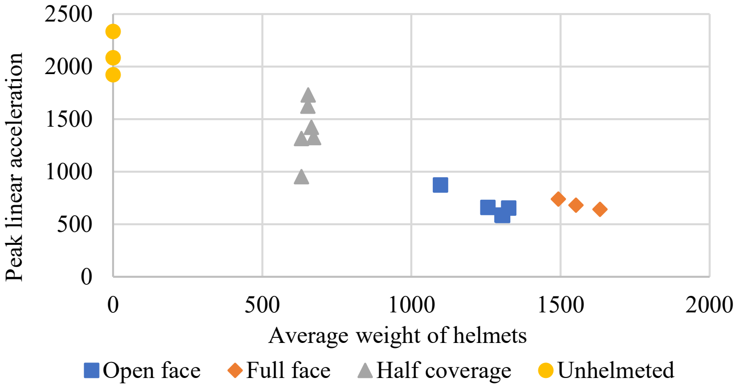
(b)

Figure 8. Boxplot display of (a) peak rotational acceleration (b) brain injury criterion

Recently, Multi-directional Impact Protection System (MIPS) technology was developed with the principle of a low-friction layer between the helmet shell and the head [56]. Yu and colleagues have taken the initiative to compare the protective performance of rotational motion among three popular technologies compared to the conventional full-face helmet. The technologies considered in their research are MIPS (low-friction layer), Flex (three-layer impact liner) and Omni-Directional Suspension (ODS). Based on their findings, MIPS was capable of providing a lower BrIC score compared to the conventional full-face helmet. At the same time, both Flex and ODS did not have a significant difference compared to the conventional helmet [57].

The analysis was further compared against the helmet weight. It is known that each helmet type has a significantly different weight. This is due to various factors, including their design, materials used, and the level of protection they provide. For example, a half-coverage helmet typically covers only a portion of the head, while a full-face helmet provides complete coverage. A full-face helmet's additional components, such as a face shield or chin bar, can contribute to its higher weight than a half-coverage helmet. These helmets can include a combination of polycarbonate, fibreglass, carbon fibre, or other composite materials to provide impact protection. The type and amount of these materials used in the helmet's shell and inner padding also can influence its weight. For instance, a helmet with more layers or thicker padding may have more weight due to the increased material density. In regards to the HIC and BrIC values, the presence of outliers for both the full-face helmet and half-coverage helmet in HIC and half-coverage helmet in BrIC indicate that there are extreme values that significantly differ from the rest of the data points. Therefore, it can be assumed to hold a different conclusion than the rest of the group.

The indicator of injury severity in terms of rotational motion, the PRA value of half coverage helmet seems imbalanced in its data dispersion in which it scatters in the range of 4,882.47 to 11,032.67. It's also worth noting that while the BrIC values may not show significant differences, other parameters such as PLA, HIC, and PRA do demonstrate variations among the different helmet types, as presented in Figure 9. In this case, the BrIC values are relatively similar across all three helmet types, ranging from 0.38 to 0.52. The lack of significant difference suggests that the different helmet types do not substantially impact reducing the risk of brain injury. It could be due to factors such as the helmets' design similarities, which do not consider rotational motion in the conventional helmet.



(a)

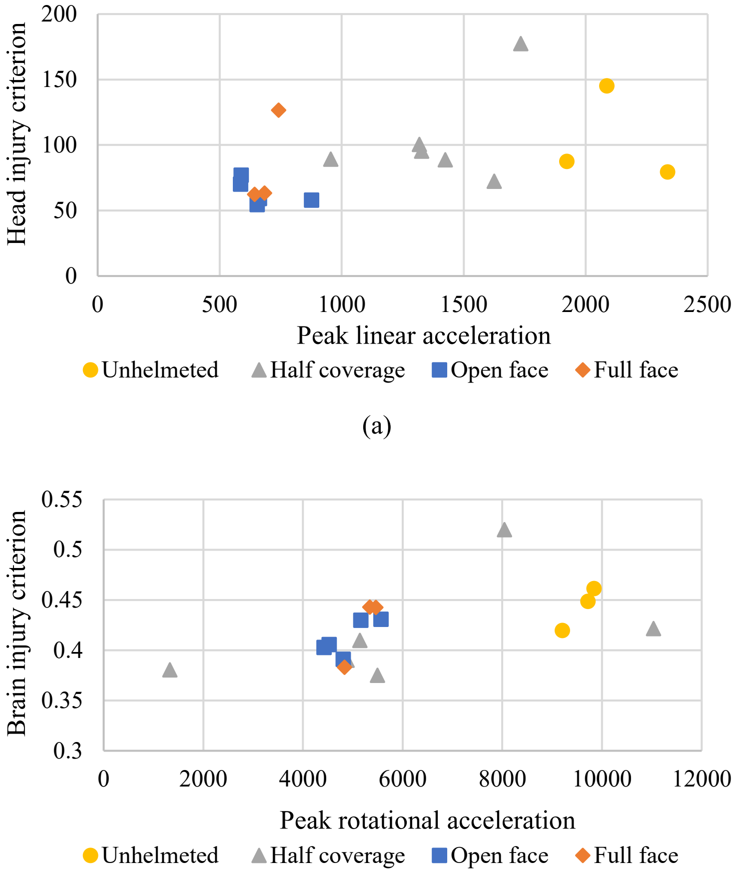
(b)

(c)

(d)

Figure 9. Tabulation of head injury predictors (a) peak linear acceleration (b) head injury criterion (c) peak rotational acceleration (d) brain injury criterion values against helmet weight

The results of this study, depicted in Figure 10, provide a clearer understanding of the correlation between HIC and PLA and the correlation between BrIC and PRA. The results indicate a surprising discrepancy between linear and rotational impact for the full-face helmet. While the full-face helmet performs exceptionally well in terms of linear impact, it performs poorly in terms of rotational impact. Similarly, the non-certified half-coverage helmet appears to perform adequately in terms of linear impact but surprisingly performs exceptionally well in terms of rotational impact. This study is a preliminary investigation of the protective performance of helmets under both linear and rotational motion impact using a pendulum swing impact machine. Including more helmets in the experiment is recommended to confirm the pattern of how helmets behave upon impact. Additionally, it is suggested to vary the impact location on the helmets to obtain a more comprehensive understanding of their protective performance.



(a)

(b)

Figure 10. Tabulation of (a) HIC vs. PLA (b) BrIC vs. PRA

4.0 CONCLUSIONS

It can be concluded that there is a significant difference between both full-face and open-face helmets with the half-coverage helmet with regards to PLA, HIC, and PRA. The helmet weight also plays a role in distinguishing the PLA result between the certified and non-certified helmet, but it is not so much different when comparing HIC, PRA, and BrIC. This study represents a pioneering effort in Malaysia to gather mechanical data comparing the protective performance of three distinct helmet types under both linear and rotational impact. Furthermore, it serves as a benchmark for evaluating the performance of helmets commonly sold in the country. These findings may align with or contradict previous research that relied on observational data such as police reports or hospital admission records of individuals involved in traffic accidents in Malaysia. The results of this study can be used to improve the safety standards of helmets in the country by providing a more accurate understanding of their performance in protecting against head injuries.

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