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RESEARCH ARTICLE

The influence of helmet certification in motorcycle helmets protective performance

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ABSTRACT - The convenience of online shopping has increased access to a vast array of helmet options and deals for motorcyclists. However, the e-commerce enables an influx of unverified and potentially hazardous helmets lacking the rigorous quality control into the market, hence, placing unaware bargain seekers at risk. The non-certified variants questions in terms of impact protection abilities because they visually look similar to certified helmets. This study compared certified full face and open face helmets against their non-certified counterparts by analysing injury predictor metrics. Using a test rig simulating 5.58 ± 0.29 m/s impacts, an anthropomorphic test device wearing both helmet types and certification statuses measured peak resultant linear and angular accelerations, head injury criterion alongside brain injury criteria scores. The data revealed comparable side and rear impact performance between non-certified and certified helmets. However, frontal impacts exposed deficiencies without certification. The non-certified full face helmets registered over twice the peak linear acceleration of certified while open face types still exceeded certified by 40 % in frontal impacts. Additionally, non-certified full face helmets indicated up to 100 % predicted concussion risks in side and frontal crashes based on the angular accelerations. The poorer frontal impact and elevated injury odds demonstrate certification's key safety advantages that certification should not be ignored while it still providing more protection than no helmet. However, individual needs to carefully select helmets due to performance differences of helmets. Riders should ultimately prioritize proven protection given the severe consequences of head trauma though non-certified may suffice for some low-risk environments.

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1. INTRODUCTION

Motorcycle helmet certification standards have been established by various countries and regions. It plays a crucial role in ensuring the safety, quality, and performance of before they are introduced into the respective markets. The tests and compliance criteria may vary across the different standards but they broadly aim to assess impact absorption, penetration resistance, retention system strength, field of vision, and many more. The example of key international standards among others include the FMVSS 218 – Federal Motor Vehicle Safety Standards in the USA, UNR No. 22.05 – United Nations in Europe, BS 6658 – British Standard Institution in the UK, AS/NZS 1698:2006 – Australia and New Zealand, and JIS T 8133:2015 – Japan [1-6]. In the case of selling imported helmet in local market, foreign manufacturers have to get their helmets certified separately to each national or regional standard before they can sell their products in those markets.

Many countries have adopted protocols from the United Nation Regulation (UNR) No. 22.05 with minor modifications. For instance, FMVSS 218 requires testing helmet impacts at speeds of 5.2 m/s and 6 m/s, while BS 6658 tests impacts between 4.6 m/s to 7.5 m/s speeds. Malaysia also adopts the UNR No. 22.05 as the basis for its national motorcycle helmet standard MS 1. The testing and certification process to this standard is overseen by two official agencies, which are the Department of Standards Malaysia (Standards Malaysia) and the Standard and Industrial Research Institute of Malaysia (SIRIM) Berhad. As the legally approved bodies, Standards Malaysia and SIRIM Berhad are responsible for evaluating and certifying all motorcycle helmets to the MS 1 specifications ensuring that only helmets meeting these stringent criteria are authorized for legal manufacture and sale within the country. The testing methodology followed by these agencies includes two main tests; a penetration resistance test and an impact absorption test. In the penetration resistance test, a steel striker weighing 4.5 kg is dropped from a height of 2,000 mm onto the helmet. The helmet fails this test if the striker penetrates through to the interior padding. The impact absorption test involves dropping the complete helmet assembly from a height of 2,150 mm onto a flat steel anvil. Instrumentation cables inside the helmet measure the peak resultant linear acceleration (PRLA) forces and derive the Head Injury Criterion (HIC) score [7]. The helmets must record PRLA under 275 g and a HIC score under 2,400 value to pass the test. Helmets that meeting these benchmarks are certified with a SIRIM label as presented in Figure 1. The label is made of a high-quality material therefore making it UV sensitive, has a micro text, and Gullouche patterns to prevent counterfeiting.

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Figure 1. SIRIM label on the experimental helmet

While the certification standards in Malaysia are a comprehensive law and standard, there are 99 countries had partial laws with exemptions based on areas, road types or engine sizes, or no helmet standards at all as shown in Figure 2. The World Health Organization reports that nearly all countries worldwide have enacted motorcycle helmet laws to some degree. However, many countries have limitations that undermine the effectiveness of these laws in reducing motorcyclist fatalities. Some nations even incorporate exemptions into their laws, leaving room for interpretation, such as confining helmet use to specific areas or roads. As of 2015, only 70 countries had comprehensive helmet regulations covering all riders, passenger types, road systems and engine sizes while mandating proper helmet use with chin straps fastened. Malaysia instituted national motorcycle helmet rules in 1973. But, motorcyclist fatality rates increased over time after the law took effect initially. This suggests helmet legislation alone may be insufficient to improve public health outcomes if other factors such as awareness, enforcement and helmet quality certification are inadequate. As Darma [8] analyzed, limited enforcement and education on helmet benefits in rural area in Malaysia during the 1970s could have contributed to lagging adoption despite the national law.

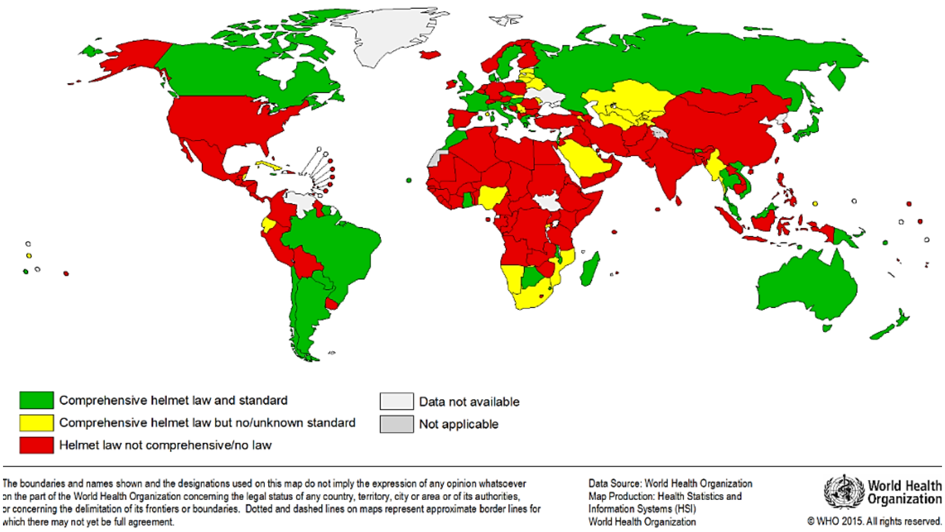


Figure 2. Global status of compulsory motorcycle helmet legislation [9]

Malaysia has witnessed rising vehicular accidents and transport-related fatalities as its population and registered vehicles increase [10]. Transport accidents ranked among Malaysia's top 5 causes of death in 2017 [11]. Motorcycles in particular are hugely popular, owing to affordability, fuel efficiency and an ability to bypass congested urban traffic. This motorcycle prevalence mirrors dense Southeast Asian neighbors like Vietnam and Indonesia too. Unfortunately, the ubiquity of motorcycles on Malaysian roads is directly linked to soaring motorcyclist deaths. Figure 3 shows motorcyclists account for over 50 % of annual road fatalities in Malaysia despite the national helmet law instituted since 1973 [10, 12-14]. This leading to thousands of lives lost each year. The popularity of illegal daredevil riding amongst youth adds risk as these groups are known may perform dangerous stunts without safety gear [15-17]. The scale of Malaysia's motorcycle deaths exceeds other regional peers.

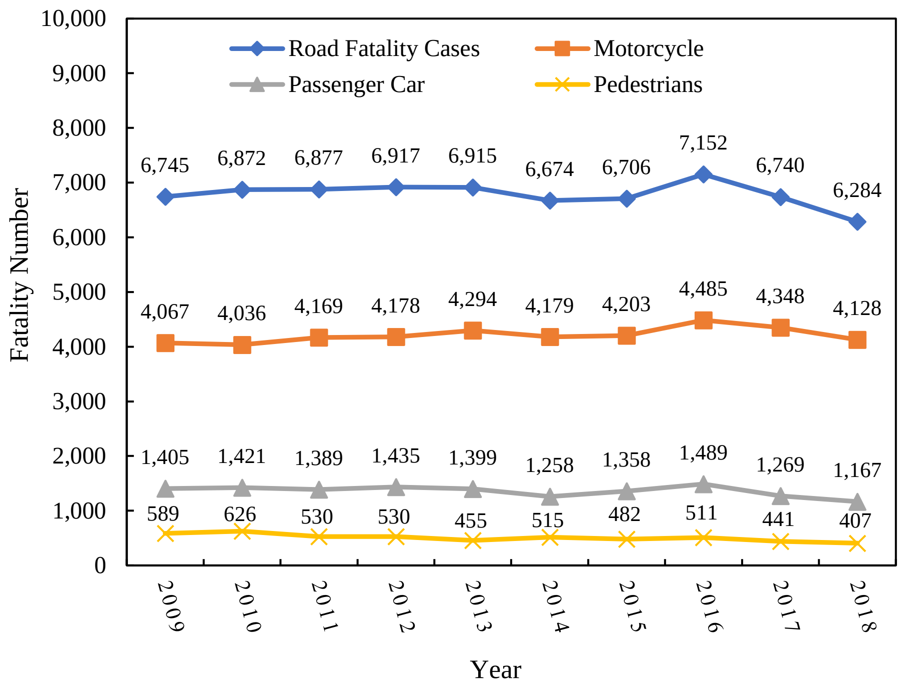


Figure 3. The Malaysian road traffic fatality cases from 2009 until 2018

Despite the current testing protocols evaluate a helmet's capacity to absorb linear impacts, there is a growing concern highlighted that angular accelerations also play a major role in traumatic brain injuries (TBI) sustained by motorcyclists in road accidents. Closed brain injuries seen in such accidents like subdural hematomas and diffuse axonal injuries are linked more to angular motions [18, 19]. Further research is required to establish suitable test methods and limits for this parameter as the present helmet testing standards do not assess angular acceleration effects. This will lead to more comprehensive testing and safer helmets with better overall head and brain protection [20]. Base on a Malaysian retrospective study in 2019, Henry Tan and colleagues reported that head injury is one of the main causes of fatality among motorcyclists although 90% of their study population wore motorcycle helmets [14]. This shows that there is also room for improvement in terms of helmet design, thereby warrants further investigation.

Another issue undermining the potential safety impacts of motorcycle helmets is the prevalence of non-certified and unsafe helmets available through online markets. The emergence of online shopping platforms has led to widespread availability of various helmet types often originating from China. Customers may be tempted by the competitive pricing, easy access, and similar stylish designs of these online helmets. At a glance, the design may look identical, for example, a non-certified full face helmet still has a chin guard and both helmet types has visor attached. It is understandable how one might be tempted to assume similar quality and protection capabilities based on the design similarities without realizing these helmets lack testing or approval from accredited agencies like Standards Malaysia or SIRIM Berhad. With not undergoing standardized impact absorption and penetration resistance tests, the ability of these unregulated helmets to effectively protect the head in accidents is uncertain. Both occupational motorcyclist case studies by Kulanthayan et al. [21] and Yellappan et al. [22] focused on non-certified open face and half coverage helmet usage, which dominated their study populations in Malaysia. It is worth noting that half-coverage helmets lack certification approval and are among the lightest-weight options in various motorcycle helmet types.

With the aforementioned problem statements, this study attempts to scientifically access and prove the protective performance of certified helmets against non-certified versions for full face and open face types. The research explores three different impact locations; side, frontal, and rear impacts. In contrast to the SIRIM certification standard testing, which entails a linear motion drop test, this study employs an oblique impact test using a pendulum test rig.

2. MATERIALS AND METHODS

2.1 Pendulum Test Rig

A pendulum test rig was developed by replicating Thorne et. al. in striking NOCSAE head form [23]. The major material used are aluminium profiles which made it strong and durable with measurement of 2.00 m × 0.62 m × 2.06 m. The test rig was designed in pendulum style for the easiness of repetitive impact. The impact by the 1.50 m pendulum occurred at the lowest gravity which resulted in the highest possible speed. The average speed recorded was 5.58 ± 0.29 m/s which was tested within five trials using SpeedClock mobile app.

2.2 The Hybrid III Anthropomorphic Test Device

Anthropomorphic test device (ATD) which normally be called crash test dummy was used to rePRLAce true human in the crash test experiment. The usage of ATD copying the impact absorption that might happen to actual humans in road traffic accidents. This study used a head and neck Hybrid III ATD attached to a PRLAtform on the ground. The Hybrid III was developed by Humanetics with association of Society of Automotive Engineers' Biomechanics Committees and the National Highway Transport and Safety Administration (NHTSA). It has been recognized widely and is used in many automotive applications and road safety testing. The Hybrid III was designed biofidelic which has size, weight, stiffness, and impact absorption and dissipation mimicking the true human. Normally the ATD is categorized into age, impact direction, size, and sex [24]. The Hybrid III head and neck are made of cast aluminium parts weighted 6.08 kg meanwhile its skin is removable vinyl skin. Its neck is part of segmented rubber and aluminium and has ability to simulate rotation flexion and extension response to the impact test.

2.3 Sensor

Three accelerometers and a gyroscope which were incorporated into the Shimmer 200g IMU sensor were PRLAced inside the Hybrid III skull at the head center of gravity to collect the raw data of linear and angular velocities that occurred during the experiment. The data collected by the Shimmer was sent directly to a laptop through Bluetooth connection. Simultaneously, ConsensysPro software version 1.6.0 recorded and screened the data on the laptop. The raw data of linear velocities was in uncalibrated mode. Therefore, it must be coded into MATLAB® 2016b software for producing calibrated data. The final output is linear acceleration for every 0.001 second in axes x, y, and z. On the contrary, ConsensysPro easily converted the raw data of angular velocities into .csv format which was easily viewed on Microsoft Excel for further analysis. The calibrated data of linear and angular motion data was prepared for the next process. The data was viewed through a line graph on the Microsoft Excel so that it can be shortened approximately at the area of impact. This needs to be done to ensure the data is easy to manage.

2.4 Signal Processing

The gyroscope in the sensor may measure the angular velocities in three-axis x, y, and z. The angular motion data in all three axes may have gone through numerical differentiation once to get angular velocities. However, this data should be filtered first through a fourth-order Butterworth filter with a cut-off frequency of 167 Hz prior to eliminating errors accumulation. The process can be achieved by installing Microsoft Excel add-in [24]. The resultant linear acceleration was calculated for data from axis x, y, and z but the highest value of angular velocities in axis x, y, and z was determined for the angular motion calculation.

2.5 Experiment Procedure

Normally, other researchers compare certified and non-certified helmets by considering half coverage helmet type as non-certified helmet. Yet, this study compares both certified and non-certified helmets in the same range of full-face helmets as listed in Table 1. Full-face helmet is a full coverage helmet where it is regarded as the safest motorcycle helmet due to its characteristics covering the entire head and has a hard shell supported chin bar near the mouth area. The impact locations were set to be at the side, frontal, and rear area of the helmets. At first, the pendulum was released at a free fall motion in the direction of the certified helmet. Next, the experiment proceeded to impact the non-certified helmet. This action was performed once only at each location of the helmet to prevent data inconsistency due to degradation of helmet performance.

Table 1. Details of the experimental motorcycle helmets

No.	Helmet Type	Weight (g)	Certification
1.	Full-Face Helmet	1675.0	SIRIM MS 1
2.		1406.5	Non-certified
3.	Open Face Helmet	1356.3	SIRIM MS 1
4.		1225.2	Non-certified

The neck of Hybrid III was decided to not be locked to the test platform with the idea that the actual human neck may not be strengthened during an impact. Hence, the Hybrid III slides after being impacted by the pendulum weight. The decision is because the victim in any actual accident may not expect the incoming impact. The situation could differ for head impact experimental procedures in sports such as soccer heading. The player may intentionally strengthen his neck before commencing soccer heading.

2.6 Data Analysis

The evaluation measures peak resultant linear acceleration (PRLA), peak resultant angular acceleration (PRAA), head injury criterion (HIC_{15}) and brain injury criterion (BrIC) as indicators of helmet effectiveness. PRLA is the first data extracted from the linear velocities to compute HIC_{15}. PRLA and PRAA is the maximum value of the resultant linear acceleration as calculated using the Eq. (1).

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

Next, data sets nearest to the PRLA were tabulated for HIC calculation. PRLA and HIC_{15} are indicators for linear motion which is commonly used in helmet international certification standards. HIC_{15} score is the summation of the biggest area under the curve within 0.015 seconds that contains PRLA. The formula of HIC_{15} given in Eq. (1).

$$HIC_{15} = \left\{(t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\}max \tag{2}$$

where $a(t)dt$ is acceleration, t_2 and t_1 are the final and initial time where HIC is calculated.

The angular motion of this study focused on PRAA and BrIC. The BrIC is based on the extensive research by Craig et al. [25], Gabler [26], and Takhounts et al. [27]. BrIC has started being given consideration in most helmet testing lately. There are many head injury predictors discussed in TBI research arenas however this study concentrated on PRLA, PRAA, HIC_{15} and BrIC only. BrIC was calculated using the formula given in Eq. (3).

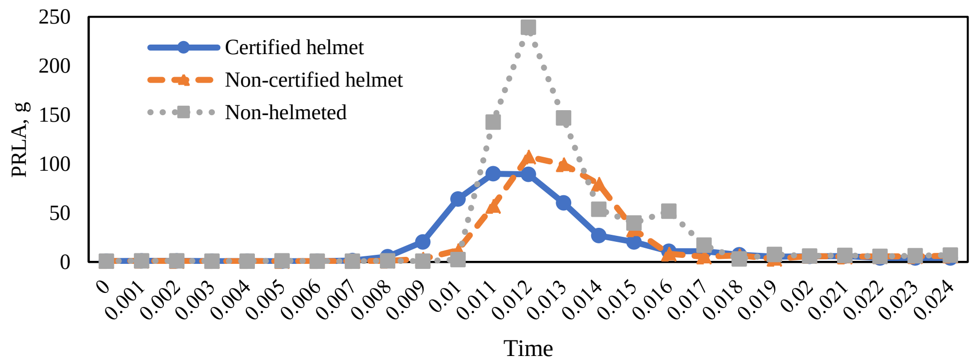
$$BrIC = \sqrt{\left(\frac{max(|\omega_x|)}{\omega_{xC}}\right)^2 + \left(\frac{max(|\omega_y|)}{\omega_{yC}}\right)^2 + \left(\frac{max(|\omega_z|)}{\omega_{zC}}\right)^2} \tag{3}$$

where $\omega_{[x,y,z]}$ is angular velocity in the direction of the x-, y-, and z-axis in rad/s. The value of critical angular velocities, ω_{xC} , ω_{yC}, ω_{zC} was provided by Takhounts et al. [27].

3. RESULTS AND DISCUSSION

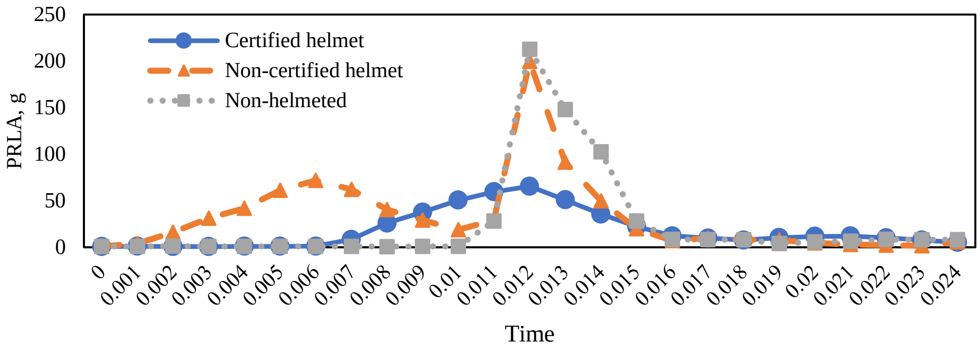
According to other researchers, non-standard or 'bogus' helmets are either non-certified by international standard regulations or designed with lack of safety precautions that usually refer to half coverage helmets. Hitherto, many articles compare the effectiveness among types of motorcycle helmet, but no article was found experimentally comparing the effectiveness between certified and non-certified of full face and open face helmets. Yadukul et al. [28] summarized the full face ISI standard helmet could give better protection as compared to full face non-ISI standard helmet based on clinical study from 2010 to 2012 in Bengaluru, India. However, the study could be argued because it was not an experimental study. The fatal motorcyclist is according to hospital case reports and no specific impact speed was determined.

This study assesses the effectiveness of full face and open face helmets of both SIRIM MS1 certified and non-certified helmets that were sold widely in the Malaysian market. Figure 4 and Figure 5 show the acceleration profile of both full face and open face helmets which were tested at three impact areas; side, frontal, and rear. For both full face and open face helmets, at Figure 4(b) and Figure 5(b), the non-certified helmets show a staggering over 100 % and nearly 40 % higher PRLA values for frontal impacts, respectively. This substantial difference raises a red flag in which signaling a potential compromise in safety standards or construction of the non-certified helmets specifically in their ability to absorb impact force efficiently from frontal impact. In contrast, the Figure 4(a), Figure 4(c), Figure 5(a), and Figure 5(c) exhibit the side and rear impact PRLA values for both full-face and open-face helmets between the certified and non-certified variants show a relatively marginal percentage difference between 4 % to 25 %. The data suggests that except for frontal impacts, there is generally not a statistically significant difference between certified and non-certified helmets in terms of PRLA values. The small differences in acceleration values imply comparable protection between both helmets status. However, certification appears to enhance helmet integrity and attenuation in frontal impact. The data shows certified helmets withstand frontal impacts much better than non-certified versions.

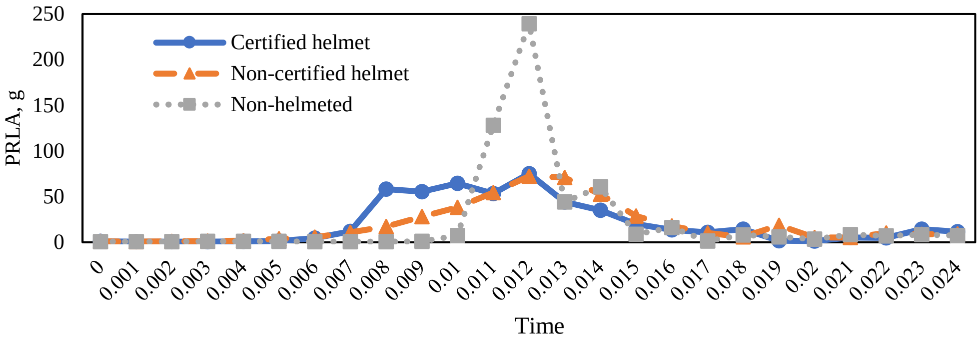


(a) PRLA at side impact for full face helmet

Figure 4. The comparison of head form linear acceleration profile between certified and non-certified helmets for full-face helmets at different locations

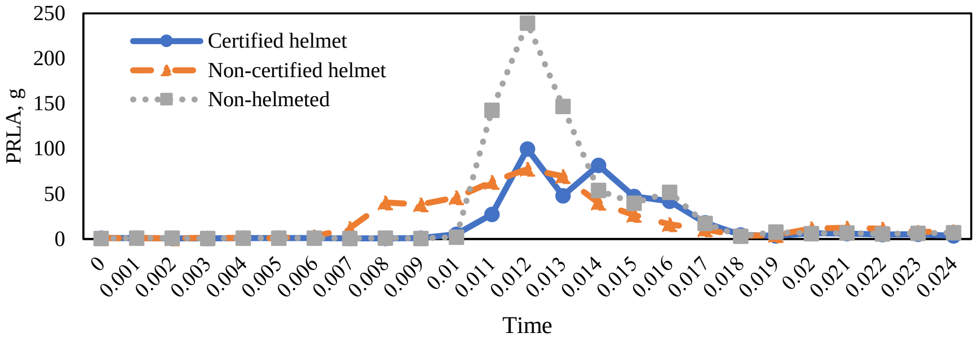


(b) PRLA at frontal impact for full face helmet

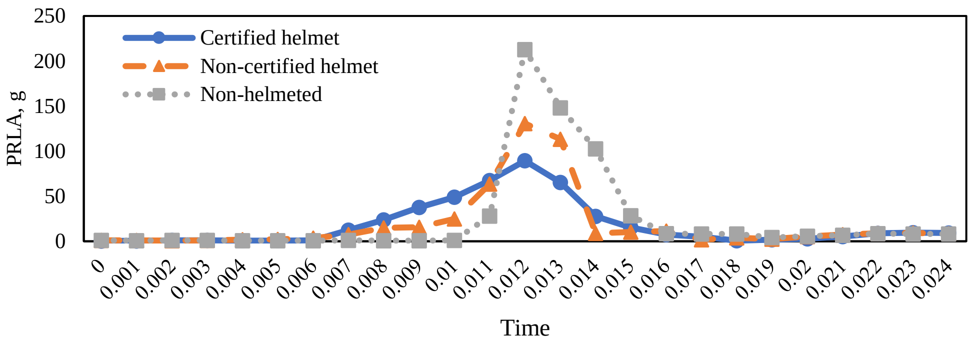


(c) PRLA at rear impact for full face helmet

Figure 4. (cont.)

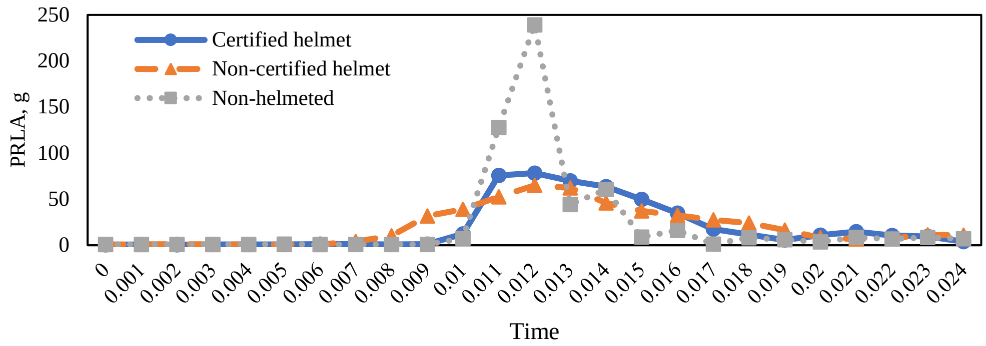


(a) PRLA at side impact for open face helmet



(b) PRLA at frontal impact for open face helmet

Figure 5. The comparison of head form linear acceleration profile between certified and non-certified helmets for open face helmets at different locations

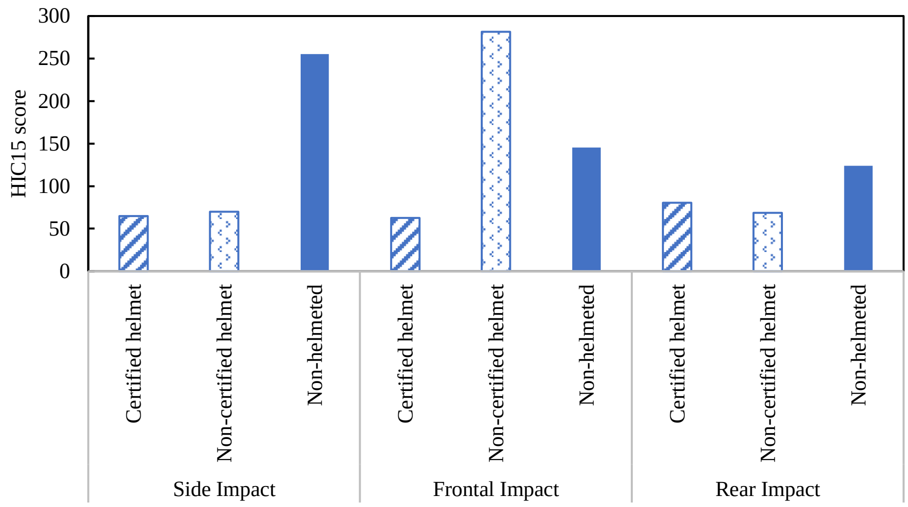


(c) PRLA at rear impact for open face helmet

Figure 5. (cont.)

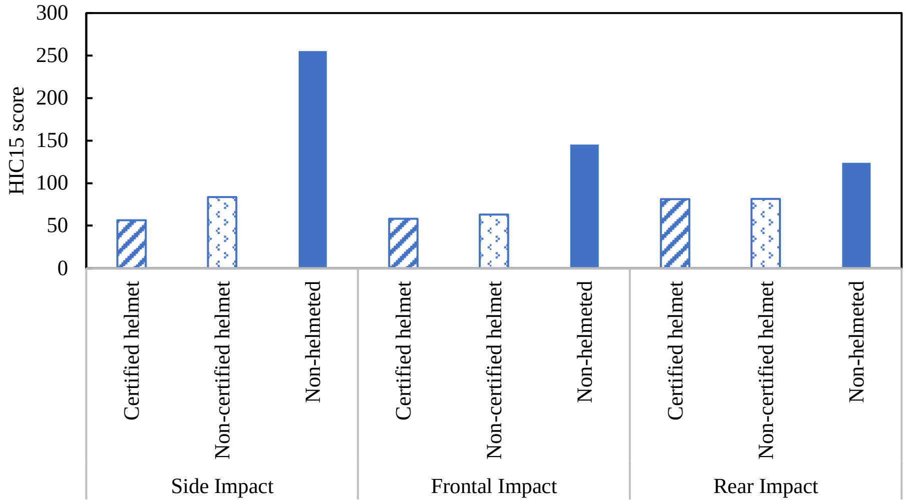
Taking into serious consideration the status of PRLA values for full face and open face helmets reveals a significant concern, particularly at frontal impact of non-certified full face helmet. The HIC_{15} score diverges as depicted in Figure 6(a) and Figure 6(b). The PRLA difference in frontal impact for full-face helmets exceeds 100% when comparing certified and non-certified helmets. The HIC_{15} score for the non-certified helmet surpasses the non-helmeted ATD by nearly 50% although the PRLA value of a non-certified full-face helmet may seem similar to a non-helmeted impact at first glance. It is known that HIC_{15} scores tend to increase along with high PRLA scores as well as longer impact duration, in which it translates to a larger area under the acceleration curve. The graph in Figure 4(b) displays a sudden 200 g spike for the non-certified helmet, consistent with the non-helmeted PRLA value peak. Both graphs also share a prominent narrow peak near the end of the 12 milliseconds timeframe. However, the graph for the non-certified full face helmet indicates a relatively minor forces during the early stages of impact. It then builds to a narrow spike of 200 g around 12 milliseconds, representing the maximum acceleration peak experienced which leading to a broader spectrum of area under curve. Despite the peaks being close in value, the graph suggests a notable dispersion in PRLA values for the non-certified helmet. This, in turn, signifies increased impact severity compared to the more consistent PRLA values observed in the non-helmeted condition.

It is important to note that the HIC_{15} graphs show unhelmeted impacts possessing the highest HIC_{15} scores of 255, 145 and 124 for side, frontal and rear impacts, respectively. This means wearing a helmet, regardless of its certification status, can possibly reduce the risk of brain injury as predicted by HIC_{15}, as listed in Table 2. Every impact location shows a significant brain injury risk reduction from 34 % up to 78 % when wearing a helmet. Shockingly though, the non-certified full face helmet produces the worst result, portraying an even greater injury risk from wearing the helmet versus not wearing one. This indicates it may be more dangerous to experience an impact while wearing a non-certified full face helmet. The negative value does not signify reduced injury risk but rather a 94 % increase in risk that could endanger the helmet wearer. This could be due to the two noticeable impact forces of 72 g and 200 g occurring at 6 and 12 milliseconds as shown in Figure 4(b). Both intense instantaneous forces likely pose a significant danger to the wearer as this dual impact force scenario is not observed in any other linear acceleration profile graph.



(a)

Figure 6. Comparison of HIC_{15} for: (a) full face and (b) open face helmet



(b)

Figure 6. (cont.)

Table 2. Brain injury risk reduction

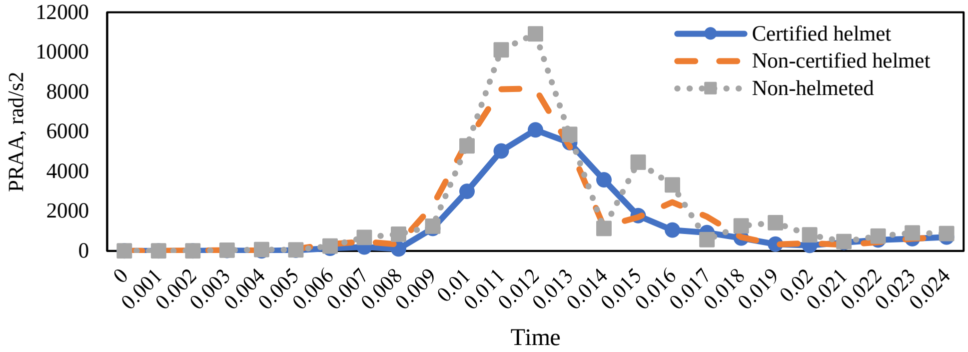
No.	Helmet Type	Injury Risk Reduction (%)			Certification
		Side Impact	Frontal Impact	Rear Impact	
1.	Full-Face Helmet	75%	57%	35%	SIRIM MS 1
2.		73%	*-94%	45%	Non-certified
3.	Open Face Helmet	78%	60%	34%	SIRIM MS 1
4.		67%	57%	34%	Non-certified

*The value of -94% does not indicate a decrease in injury risk; instead, it represents a 94% increase in risk which potentially endangering the wearer of the helmet.

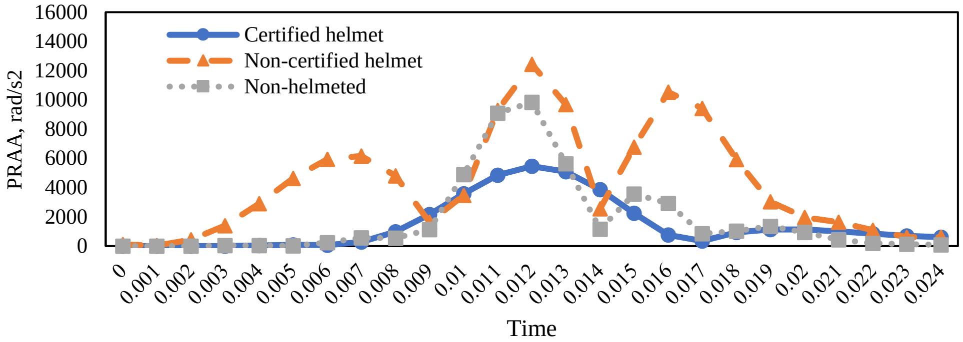
Nevertheless, the comparison of brain injury risk reduction can only be calculated with linear motion parameters. This limitation arises because the current international standard certification exists only to evaluate linear motion parameters, as mentioned in the earlier section of this article, which consists of PRLA value and HIC_{15} score only. As discussed previously, it is crucial to highlight that the helmets subjected to experimentation in this study are conventional ones readily available in the market. These helmets are designed to comply with existing certification standards, primarily emphasizing linear motion impact. Conventional helmets feature interior padding foam or liners glued directly to the inner of outer shell which allows significant angular accelerations to still be transferred to the head on impact. Previous research confirms that high rotational velocities and accelerations persist wearing conventional helmets that carrying risk of concussions or other TBIs [29]. Figure 7 and Figure 8 show that even certified helmets displayed interchangeably high and low PRAA values at the various impact locations in this regard. Notably, some non-certified helmets raise concerns by revealing significantly higher PRAA values, particularly in side and frontal impacts for full-face helmets and frontal impacts for open-face helmets.

Specifically, the PRAA measured in this study demonstrate considerable angular head motions wearing both certified and non-certified conventional motorcycle helmets. Rowson et al. [29] presented an injury risk versus PRAA graph, hence, offering insights into the percentage of concussion probability associated with football sports impacts. Concussion probability was derived from the PRAA data and is summarized in Table 3 in this experiment. A notable observation was made upon comparing the PRAA results from this study with the graph. The concussion probability reaches 100 % without a helmet. However, the concussion probability falls within the range of 15 % to 36 % with a certified full face helmet. In contrast, the concussion probability can soar up to 100 % for side and frontal impacts with a non-certified ful face helmet, thus, indicating a heightened risk of concussions in numerous scenarios.

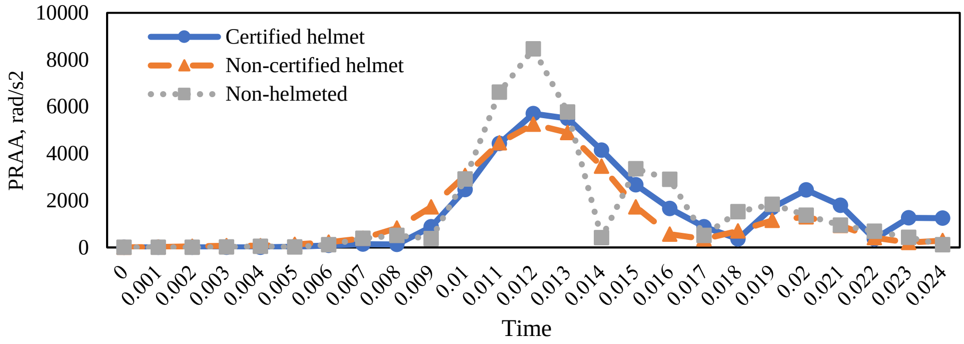
Certified full face helmets consistently exhibit the lowest concussion probabilities across all three impact areas, therefore, underscoring their effectiveness in reducing the likelihood of concussions. Conversely, non-certified full face helmets perform the least favorably by predicting a minimum 100 % concussion risk in side and frontal impacts. Certification appears to confer significant benefits, particularly in frontal impacts for open face helmets where it substantially diminishes the likelihood of concussions compared to the non-certified counterparts. However, it's crucial to note that the certification of helmets, as emphasized earlier, may not be directly applicable in this context due to its focus on linear motion only. This limitation prompts a nuanced interpretation of the results recognizing that certification standards primarily address linear motion parameters, such as those considered in this study.



(a) PRAA at side impact for full-face helmet



(b) PRAA at frontal impact for full-face helmet



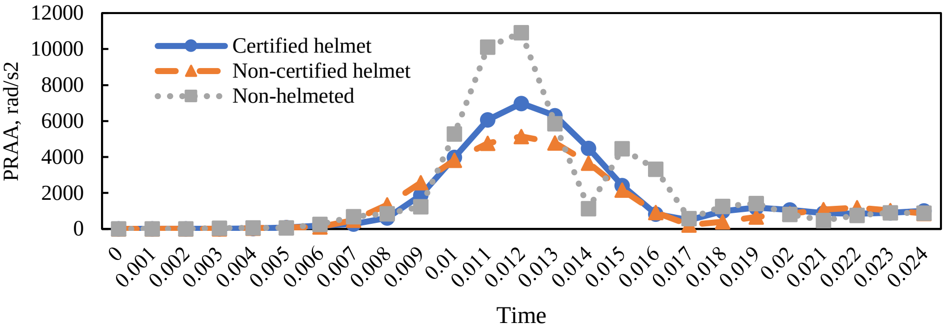
(c) PRAA at rear impact for full-face helmet

Figure 7. The comparison of head form angular acceleration profile between certified and non-certified helmets for full-face helmets at different locations

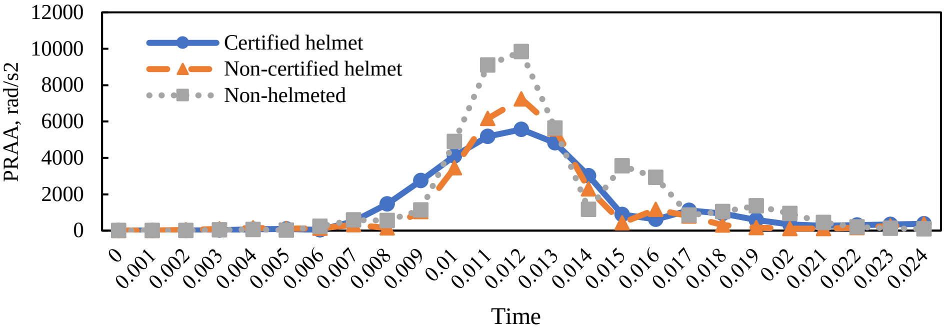
Table 3. Concussion probability [29]

No.	Helmet Type	Concussion Probability (%)			Certification
		Side Impact	Frontal Impact	Rear Impact	
1.	Full-Face Helmet	36%	15%	20%	SIRIM MS 1
2.		100%	100%	11%	Non-certified
3.	Open Face Helmet	73%	18%	0%	SIRIM MS 1
4.		8%	85%	0%	Non-certified

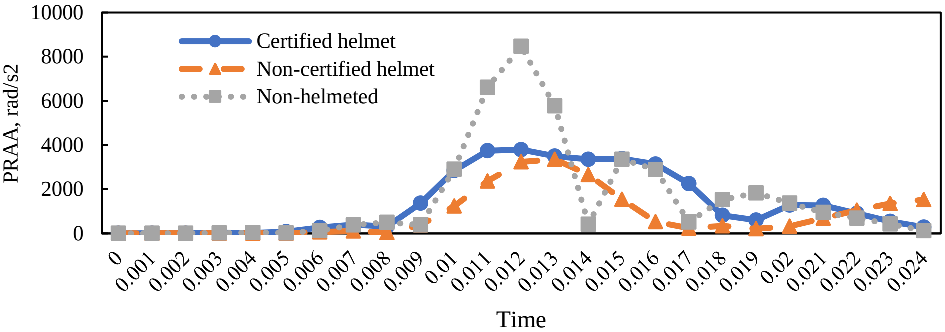
Surprisingly, Figure 9 illustrates that certified, non-certified, and even unhelmeted conditions all exhibited similar BrIC scores. This observation holds true suggesting that the helmets used in the study lack the technological features necessary to mitigate angular injuries. A crucial factor contributing to angular acceleration is the coefficient of friction. These studies suggests that reducing friction between the helmet and the head or between the helmet and the impact surface, could potentially improve protection against rotational motion [30–32]. Both Figure 9(a) and Figure 9(b) emphasize that side impact locations pose a heightened risk of severe injury in terms of angular motion. This unintuitive result suggests the limited rotational motion attenuation offered by any of the conventional helmets whether passing certification requirements or not. Their fundamental designs simply do not account for angular impact forces. This is evident from the consistently higher BrIC scores for side impacts compared to frontal and rear impact locations. Furthermore, the BrIC scores indicate minimal differences between certified and non-certified helmets when compared to the unhelmeted ATD which underscoring the need for advancements in angular injury prevention technology in both helmet categories.



(a) PRAA at side impact for open face helmet



(b) PRAA at frontal impact for open face helmet



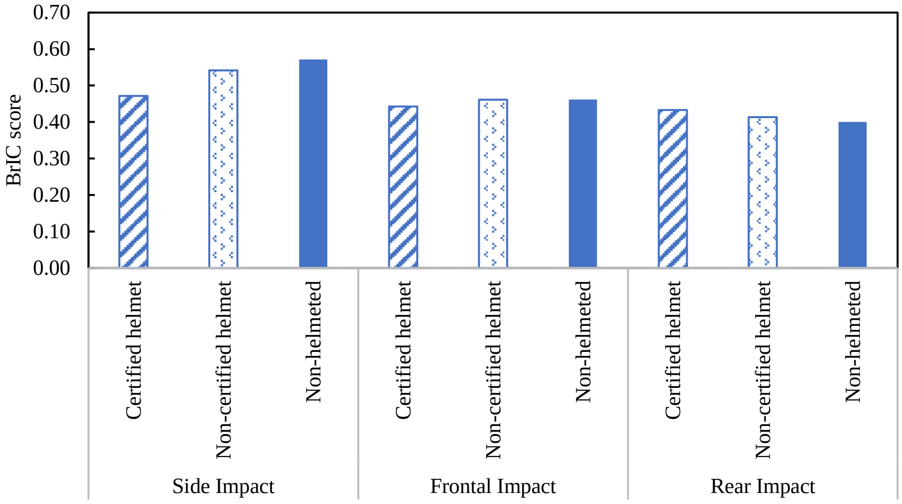
(c) PRAA at rear impact for open face helmet

Figure 8. The comparison of head form angular acceleration profile between certified and non-certified helmets for open face helmets at different locations

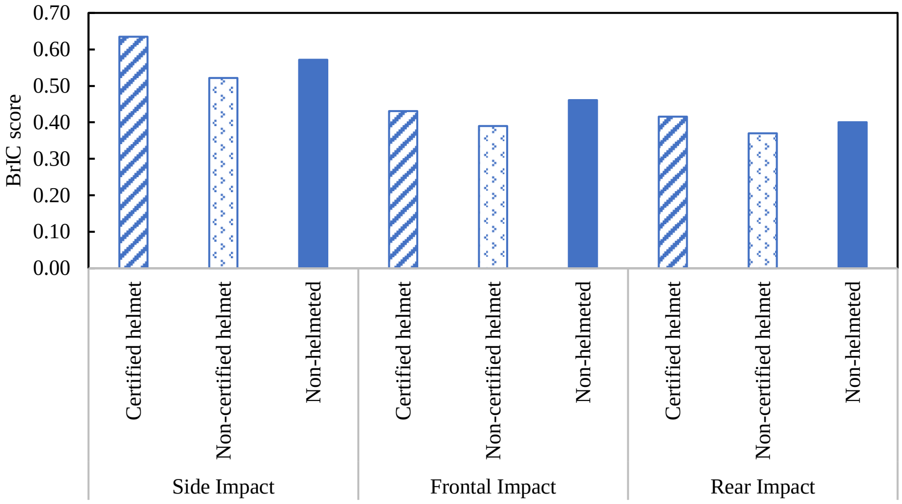
Recent technologies like Multi-directional Impact Protection System (MIPS) or Phillips Head Protection System (PHPS) offer promising approaches to address this limitation by incorporating low friction layers between helmet layers. These systems displayed reduced rotational accelerations between 25-50 % compared to standard helmets [31, 33–35]. Implementing such new technologies into future helmet standards and designs could better account for comprehensive accident injury mechanisms. Overall, the high PRAAs coupled with insignificant BrIC improvements emphasize that prioritizing angular motion safety could optimize helmets for more complete rider protection.

Overall data shows that non-certified helmets performed comparably to certified versions in side and rear impacts for both helmet types at linear motion impact. However, frontal impacts exposed concerning deficiencies in non-certified models with PRLA exceeding certified helmets by 100 % and 40 % for full face and open face types respectively. Furthermore, non-certified full face helmets indicated high concussion risks up to 100 % probability in side and frontal impacts for angular motion impact. Though offering protection over no helmet, this poorer frontal impact attenuation and elevated injury likelihood with non-certified helmets demonstrates key advantages of proper certification.

Apart from that, the certification method is more crucial and could be improved. Many helmets are considered to fulfill the requirement for certification purpose because the current laboratory testing for the helmet certification evaluates linear impact only. However, its performance in the real accident event is questionable because the certification method does not consider angular motion during the accident. Henceforth, the certification body is urged to introduce angular motion elements, thus catering for a more realistic accident event.



(a) BrIC for full face helmet



(b) BrIC for open face helmet

Figure 9. Comparison of BrIC between certified and non-certified helmet

4. CONCLUSION

In conclusion, this study's findings reveal certification provides meaningful safety benefits while non-certified motorcycle helmets available in the Malaysian market are not necessarily of poorer construction quality compared to certified options. The comparable performance between helmet types in side and rear impacts suggests adequate integrity of non-certified models to attenuate certain impacts. However, diminished frontal impact absorption indicates potential vulnerabilities without proper testing and approval. Considering frontal collisions among the most lethal and prevalent accident types, the considerably higher accelerations and injury risks observed make a compelling case for greater enforcement against non-certified helmet distribution and use. Additionally, with helmet testing standards currently emphasizing only linear impact, integrating angular acceleration considerations through advanced helmet technologies could enhance protection for all riders. Ultimately, accessing both certified and non-certified variants experimentally substantiates key advantages of current certification protocols while prompting standards evolution to address angular motion and motivate universal certified helmet adoption through stern legislation and public awareness.

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