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Child Helmet Efficacy for Motorcycle Use in Malaysia

Azhar Hamzah
Yahaya Ahmad
Wong Shaw Voon, PhD

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MALAYSIAN INSTITUTE OF ROAD SAFETY RESEARCH

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Abstract

With the ever increasing popularity of motorcycle as a mode of transport in Malaysia and several other countries in Southeast Asia, the demand for an efficient system of protection is highly anticipated. The inadequate protection afforded to the users has heightened our concern for a better passive protection system such as the safety helmet as a preventive measure to reduce or eliminate injuries and/or fatalities.

Numerous scientific literatures have proven the importance and effectiveness of legislation, enforcement and helmet standards in improving the safety and health of motorcyclists on the road. However, it is noted that very limited materials are available concerning injuries among children in relation to motorcycle accidents. Furthermore, issues such as age limit and physical requirements for motorcycle riding need to be studied as a precursor to any review exercise of motorcycle legislation and standards.

Comparative studies on helmet standards indicated the influence of size and mass of safety helmets in relation to injury risk. A number of experimental models developed previously have noted that the bio-mechanical limits and anthropometry between adult and children are different and the injury limits of children are a function of age. On the other hand, experimental tests on helmet demonstrated the equivalent performance of child and adult helmets, thus undermines the disparity in injury tolerance.

Another concern is the availability and accessibility of various designs of children helmets in the market, which could be categorised into standard-compliant, non-standard and game/toy helmets. The standard helmets may have some limitations in sizes to provide a 'good-fit' for children of lower age group, while the non-compliant one reflects distinct differences in configurations, constructions and materials, which contribute to their inferior capability to provide optimal protection in road crash.

There is an undeniable need to protect children travelling on motorcycles on the road. The establishment and introduction of appropriate protection systems, helmet standards and motorcycle regulations will help to realize our vision of safer travel for all and for children in particular.

1.0 Introduction

Motorcycles are a common and popular mode of mobility in Malaysia and other Asian countries such as Indonesia, Thailand and Vietnam. In Malaysia, more than half of the registered vehicles are motorcycles, while in Vietnam, the figure is much higher, at 95% (WHO 2009). The economic advantage of owning and maintaining a motorcycle, combined with its physical size which allows easy manoeuvre in everyday traffic are strong factors that led to its popularity. In most instances, motorcycles are commonly used to transport not only the rider and passenger, but also multiple passengers, as well as products and goods.

Although motorcycles offer a lot of benefits, they provide limited or no physical protection to motorcyclists and their passengers, making them vulnerable to injury when they are on the road. Children of certain age, with limited physique such as weight and height are especially more susceptible as most of the times they ride as passengers. A World Health Organization (WHO) statistics reveals that road traffic accident (RTA) injuries is the leading cause of death for people in the age group of 15–19 years, and the second leading cause of death among children 5–14 years old 29 [WHO 2009]. In Malaysia, statistically, for the year 2005 to 2007, more than 3 600 fatalities were recorded annually on average (MROADS 2009). It was also reported that among children aged 1 to 18 years old involved in motorcycle accidents, 10.5% were fatal (1 497 of 14 216). However no details were provided on the cause of fatality.

A recent observational study undertaken by Malaysian Institute of Road Safety Research (MIROS) around urban and suburban areas of Klang Valley Malaysia indicated that generally, child helmet is readily available in most motorcycle sales and service outlets. As a general rule, child helmets commonly used for motorcycling could be categorised into two distinct groups: standard and sub-standard. The standard helmet is normally tested and complies with MS1:1996 helmet standard (Malaysian Standards 1996), while the other was basically produced to cater for games and recreational activities such as bicycling and not designed for motocycle use. Technically the latter helmet has to be opted out from road use.

It is noted that the available helmet in the market may be limited in terms of alternative sizes to cater for the various children age groups. It is possible that some children are using an incorrectly fitted helmet, either oversize or undersize, when they are on motorcycles. This inadvertently may exposed them to increased risk of injury should they involve in road crashes. This is supported by a study at the Children Hospital of Philadelphia (CHOP) which showed that anthropometric data for adult and children are different, indicating that adult helmets may not be suitable for child use.

Another issue related to child helmet requirement is the appropriate age limit for children to ride as passengers on a motorcycle. This may have to be determined in advance to ensure a more practical approach in determining the appropriate helmet characteristics and its protective and performance requirement. In line with that, it is anticipated that motorcycle policies may require some amendments to suit the new potential requirement. Any shortcomings or inconsistencies may hamper the enforcement effort, as evidenced by the case reported by WHO (WHO 2009) in Vietnam, where inconsistency in helmet law and road legislations concerning children resulted in difficulty in enforcement activity.

Therefore, this present work will attempt to evaluate the children head protection needs when riding on a motorcycle and to determine whether these needs are sufficiently represented in the existing motorcycle regulations and policies in Malaysia. Furthermore the report will also look at the prevalence of use of helmet among children passengers and the possibility of establishing the appropriate safety requirement for motorcycle riding.

2.0 Overview

In Malaysia, motorcyclists suffered the highest fatality rate annually among all types of road users, ranging from 3 400 to more than 3 600 (MROADS 2009). Children of varying ages, as riders or passengers were among these casualties (19–20%). To determine whether children head protection needs while riding motorcycles are adequately addressed, a review of literatures, legislations, accident statistics and helmet standards was carried out.

2.1 Literature Review

The effectiveness of helmets in reducing the risk of fatality and injury severity is well documented. For instance, Moskal *et al.* (2008) concluded that proper helmet use significantly decreased the risk of head and facial injuries. A retrospective studies by Deutermann (2004) and Dee (2009) reported that helmet were 37% and 34% effective in preventing fatality in the United States. These findings are further supported by a recent study by Liu *et al.* (2008) in Cochrane Reviews which clearly stated that proper helmet use reduces the risk of head injuries by 69% and fatalities by 42%. However, the use of sub-standard or non-compliant helmet could be detrimental in a road crash. This is evidenced through a study by Asa *et al.* (1999) in the US which concluded that wearers of non-standard helmet more frequently suffered head injuries and at greater severity in road accidents than those wearing standard helmets.

Scientific materials concerning child helmet use related to motocycles are very limited. However studies with respect to children and bicycle helmets are common and widely available (Thomas *et al.* 1994; Maier *et al.* 1995; Le Blanc *et al.* 2002) . This is a clear indication that the subject is understudied. Nevertheless, few available evidences showed children involvement in traffic fatalities is discussed. A research by Kanchan *et al.* (2008) pointed out in a retrospective study that head injuries alone were the cause of fatalities in the majority of road traffic incident (82.1%) involving schoolchildren.

Similarly, a local research by Rohana Ong *et al.* (1998) also discovered that in a prospective observational study that vehicle related injuries were prominent among children between 5 and 14 years of age where none of the victims were using protective or restraining device, probably due to lack of adult supervision or poor enforcement activities.

From the injury perspective, there are few studies around child injury and motocycle crashes. Relevant studies on injuries on adult motorcyclists are available. A survey in Vietnam by WHO in 2008 revealed that the low helmet use rate was due to the fear of neck injury and it was the most important

reason given by parents (67%) (Hung *et al.* 2006). In addition, plenty of studies (Kasantikul *et al.* 2003; O'Connor 2005) also have shown that there was no significant difference in the odds of cervical spinal cord injury among unhelmeted and helmeted motorcycle accident victims. This is further supported by studies in the US that highlighted that statistically, there was no relationship between helmet use and cervical or thoracic fractures (Goslar *et al.* 2008). Additionally, Moskal *et al.* (2008) also established that use of helmet does not increase the risk of neck injury.

In addition, experts' convention in the Children's Hospital of Philadelphia (CHOP) in 2003 concerning paediatric head and neck injuries has acknowledged and identified few key issues for consideration in the development of child helmet standards. In brief, head protection system for children use shall take note of the differences in anthropometric and biomechanics and injury patterns between children and adults and helmet design constraints.

All the findings and evidence thoroughly supported the benefits of helmet use to the wearers. However, it is noted that most of the data and subjects in the studies were adult and it is known that adult and children anthropometry are different (Arbogast *et al.* 2003). Therefore it is possible that findings from adult helmet research may not be applicable to children, and further research should be undertaken to establish child head protection needs.

2.2 Legislation

A comprehensive review of regulations and policies relating to motorcycle laws reveals that very few countries specify a minimum age for a child riding as a passenger on a motorcycle. Additionally, the definition of child physical requirements to ride as passenger is also rarely available. For further insight, some of the sighted road rules are listed in Table 1.

Table 1 Comparison of motorcycle passenger regulations

Country	No of passenger	Passenger age limit	Helmet requirement
Malaysia	Only 1 passenger allowed	No requirement	Yes
Vietnam	No requirement	No requirement	Yes
USA, states	No requirement	Varies from >5 to >8 years	Yes
Australia	No requirement	≥8 years, unless in a side car	Yes

In general, all available regulations express the requirement for helmet use for riders and passengers of motorcycles. Malaysian regulations explicitly address the prohibition of multiple passengers on motorcycles but lacks the element in specifying the minimum passenger age or physical requirement.

This absence may create misunderstanding or misinterpretation among users and may later create complexity in enforcement activities. In contrast, some countries specify the minimum age for passenger for example, ≥8 years in Australia but the number is numerically inconsistent and the rationale of age derivation could not be clearly identified.

2.3 Motorcycle Accident and Casualty

In Malaysia, all road traffic accidents records are collected by the Royal Malaysian Police (PDRM). The records are then made available to the Malaysian Institute of Road Safety Research (MIROS) database system for research purpose. Based on data provided, from 2006 to 2008, the reported children casualties in motorcycle accidents averaged at 4 849 (Table2) annually. Out of this, 10.5% (511) resulted in death while the remaining ended up with serious or slight injuries (26.3 and 48.6% respectively).

Table 2 Motorcycle accidents casualty (Children 1–18 years), Malaysia (*Source:* MIROS)

Severity	2006	2007	2008	Average percentage, %
Fatal	485	469	578	511 (10.5)
Serious	1 314	1 223	1 288	1 275 (26.3)
Slight	2 470	2 330	2 269	2 356 (48.6)
Not injured	707	628	785	707 (14.6)
Total	4 976	4 650	4 920	4 849

Figure 1 shows that casualties among children aged one to six years as a result of motorcycle accident stands at 2.8% (397). For age seven to 12 and age 13 to 18 years, the figure was 4.7% and 77.5% respectively. The number of casualties seems to increase relatively with age, likely due to the fact of increased exposure to travelling. However, more detailed accident information such as crash mode, helmet use, helmet type, single or multiple passengers and passenger position on motorcycles and also data of injury outcome is not readily available.

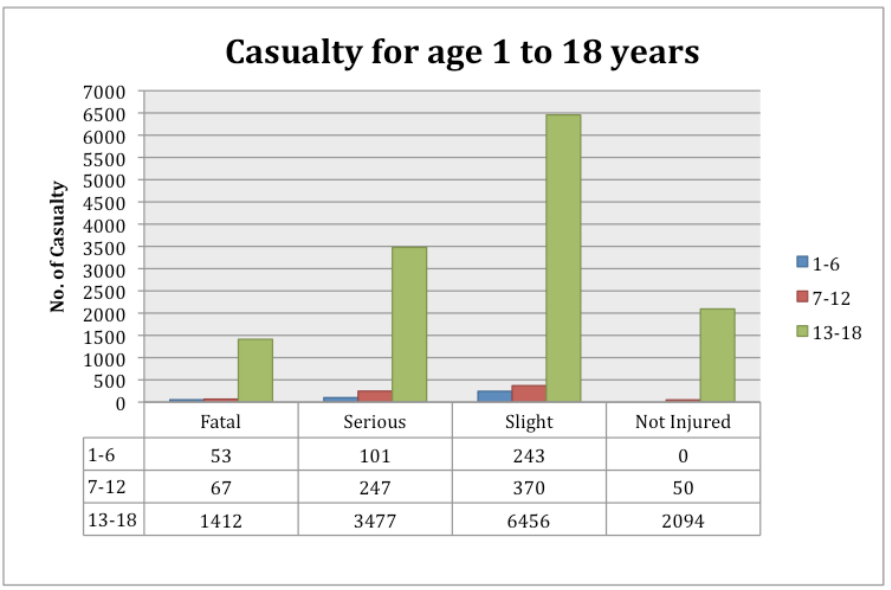
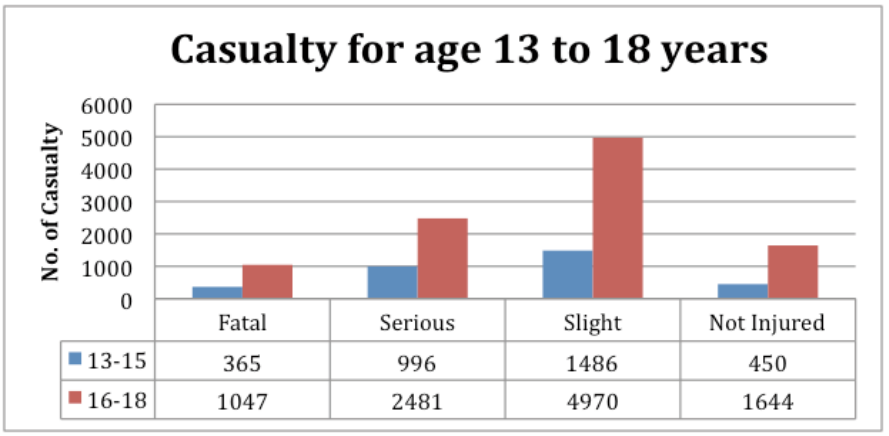


Figure 1 Children casualties by age group (*Source:* MIROS)

In Figure 2, casualties for age 13 to 18 years are divided into two categories –age 13 to 15 and age 16 to 18 years. The data is divided in such a way because motorcycle licensing age starts at 16 years old in Malaysia. In detail, the number of fatalities for those between 16 and 18 years old is approximately 2.9 times higher than the 13–15 years age group. However, for the age group from one to six years and seven to 12 years, fatality percentages were 3.5% (53) and 4.4% (67) respectively, of which, more than 88% rode as passengers. The remaining 12% rode as riders, illegally.



	Fatal	Serious	Slight	Not Injured
13-15	365	996	1486	450
16-18	1047	2481	4970	1644

Figure 2 Children casualties for 13–18 years age group (*Source:* MIROS)

The trend in Figure 3 shows a ratio of rider to passenger casualty, which is approximately five to one. The drastic shift from passenger to rider casualty maybe related to the licensing age (starts at 16 years old), higher exposure to motocycle riding and brife riding experience.

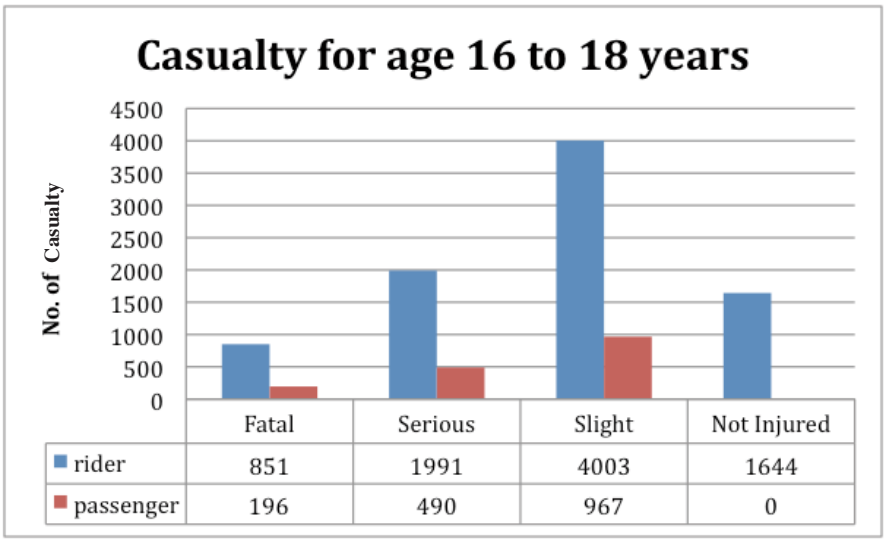


Figure 3 Children casualties for 16–18 years age group (*Source:* MIROS)

2.4 Safety Helmet Standards

A comprehensive literature search shows that specific performance standards and test protocols for child helmets for road use is limited. For instance, in US, the establishment of the Snell/FIA helmet standard is meant for motorsport and off-road use, and not for on road application. Nevertheless, a few standards addressing child helmet for motorsports and recreational activities are presented in Table 3 which shows the comparison of some of the common test parameters.

Table 3 Comparison of helmet standards

Standard	Snell/FIA CM2007 Std for Protective Headgear	MS1727:2004 Impact protection helmets for young children	MS1:1996 Spec for Protective Helmet for Road User	Malaysia Patent PI 20031295 Safety Helmet for Children	ECE R22 Standard for Helmet and Visors	Vietnam Technical Regulation for Protective Helmets QCVN 2:2008	Europe-Child Standard Bicycle Helmet	Canada Bicycle Helmet Standard	Australia/NZ Bicycle Helmet Standard
Scope	Children motorsports use	Motor vehicle free environment, <7 yrs old	Vehicle user	Children	Moped and motorcycle use	Road users and moped	Bicycle, child	Bicycle, child	Bicycle, child
Size, cm	<49–59	50–62 Headform	50–62 Headform	45–60	50–62 Headform	<50, 50–52, >52	A,E,J,M,O Headform (50–62)	A,E,J Headform (50–57)	O,J,M,E, A,AA Headform (<50–62)
Mass, g	1 000–1 300	No requirement	No requirement	500–1 000	No requirement	**Full face**, * L <1 500 M&S <1 200 **Open and ½ shell** L <1 000 M&S <800	No requirement	No requirement	300–700
Performance i. Impact test, m/s	3.8–7.75	4.57–5.42	5.94–6.42 (1.8–2.1 m)	5.94–6.42 (MS1:1996)	5.5–7.5 (8.5 for oblique test)	4.8–6	5.4 (1.5 m)	<5 yrs 50J, <200 g 67J, <250 g >5 yrs 55J, <200 g 80J, <250 g	5.33–5.94 (1.45–1.8 m)
Max. head deceleration, *g*	< 290 g	<250 g	< 300 g	<200 g	<275	<225 g (for <50 cm circumference) <300 g (for ≥50 cm circumference)	<250 g No requirement	No requirement	<300 g No requirement
HIC value	No requirement	No requirement	No requirement	No requirement	<2 400	No requirement	No requirement	No requirement	No requirement
ii. Penetration drop height, mm	3 000	No requirement	2 000	No requirement	No requirement	2 500	No requirement	No requirement	No requirement
mass of striker, kg	3.0		4.5	No requirement	No requirement	3.0			

*Note: * L means Large: > 52 cm circumference, M medium: 50 to 52 cm circumference, S small: <52 cm circumference*

In review, for motorcycle use, only Snell/FIA, Vietnam Standards, and Malaysia Patent address sizes smaller than 'A' headform size (50 cm). Since the Snell/FIA standard is specifically meant for motorsport purpose, the option for a child helmet standard for road use is limited. It is also noted that Malaysian Standard, MS 1727, requires a minimum size of 50 cm which may not satisfactorily correlate to the head size of children younger than seven years old. In conjunction to that, based on WHO head growth standard, the 50th percentile head circumference measurement of children age two to five years old ranges from 47.3 to 50.7 cm. A look at Vietnam growth chart showed that the 50th percentile head size for children age five is less than 51 cm (WHO 2009). A study in 2003 at Malaysian schools found that the average head size is 52.5 cm with the smallest being 48 cm and the largest 59 cm (Malaysian Patent Application 2003). A study in Turkey pointed out that children age six to 12 years have a head circumference range of 50.8 to 53.9 cm (Karabiber *et al.* 2001). This figure implies the potential need for a wider range of helmet sizes for children use, especially for those under the age of six.

In terms of weight or mass of helmets, the minimum standard for the smallest size is observed to be less than 800 g for motorcycle use and 300 g for bicycle use. A recent random check carried out by MIROS in 2009 in Klang Valley, Malaysia, discovered that MS1:1996 Standard-compliant child helmet weighs approximately 800 to 900 g. However, this figure is twice or greater as heavy when compared to what is available in Vietnam market, as shown in Table 4. This obvious difference is due to the variation in the extent of protection coverage in which Vietnamese standards allow half-shell helmets, while MS1 does not (Malaysian Standards MS1:1996).

Table 4 Brands and sizes of helmets available in Vietnam (*Source*: Moskal *et al* 2008)

Brand	Size	Head Size (cm)	Helmet weight
PROTEC	XS	48–51	0.23 kg
PROTEC	S	50–52	0.34 kg
ANDES	S	50–53	0.4 kg
PROTEC	M	53–55	0.36 kg
ANDES	M	54–56	0.55 kg
EVO	M	56.5–58.5	0.4 kg
EPIC	M	56.5–59.5	0.45 kg

In addition, for motorcycle helmet impact performance standard, the head acceleration measurement in term of 'g' is the lowest in Malaysia (Malaysian Patent Application 2003), at <200 g. However, the relationship of this value to the child injury tolerance and injury severity remains to be determined. Another major difference is the absence of Head Injury Criterion (HIC) requirement in almost all standards except the European Regulation, ECE R22, which specifies HIC value of less than 2 400 (UNECE 2004). HIC is a measurement established to evaluate potential head injury in the event of head impact. It takes into account, in the calculation, the head acceleration and the time interval of the acceleration. In normal impact testing, these variables are derived from accelerometers embedded in the headform centre of gravity which is placed inside the safety helmet. For penetration test, only motorcycle standards address the requirement and none from the listed bicycle helmet standards.

3.0 Injury and Epidemiology

There is evidence that age is a strong predictor of serious injury from motor vehicle trauma (Newgard 2008). It was pointed out that serious head and extremity injuries gradually increased with age, in a non linear fashion. Children's physiques are structurally different from adult. For instance, many features such as head to body proportion, location of centre of gravity, neck and skull strength and cranial development are all different from adult (Gorrie *et al.* 1998). Therefore, children may possibly have a different tolerance to acceleration/deceleration forces.

3.1 Injury Mechanism

A helmet is the most common form of head protection for motorcyclist. In designing a helmet, the head injury mechanism must be explicitly understood in order to devise a suitable helmet that can provide adequate protection to the wearer. The two common types of injury that are related in helmet design and wearing are brain injury and neck injury (cervical trauma).

3.1.1 Brain injury mechanism

The brain is the most critical organ that must be protected from trauma. This is simply because anatomic injuries to its structures are currently irreversible and the consequences of injury can be devastating.

Mechanical injury to the brain can occur in a variety of ways which include (1) direct contusion of the brain from skull deformation or fracture, (2) brain contusion from movement against rough interior surfaces of the skull, (3) reduced blood flow due to infarction or pressure, (4) indirect (contrecoup) contusion of the brain opposite the side of the impact, (5) tissue stresses produced by motion of the brain hemispheres relative to the skull and each other, and (6) subdural hematoma produced by rupture of bridging vessels between the brain and dura mater. The latter three mechanisms are hypothesized to result from both impact and non impact (inertial acceleration) head injury (Ommaya 1985).

There are three types of experimental models used to develop a reproducible model of trauma that exhibits anatomic, physiologic, and functional responses similar to those described clinically. The experimental brain injury models are divided into three general categories, namely head impact, head acceleration, and direct brain deformation (Melvin and Lighthall 2002).

3.1.2 Neck injury mechanism

Another injury mechanism that needs to be understood is the cervical trauma. The cervical spine is very complex, both from the mechanical and structural point of views. The human neck contains vital neurological, vascular, and respiratory structures as well as the cervical vertebrae and spinal cord.

The study of the cervical spine trauma has evolved from a variety of institutions and sources but there are still some confusions in understanding injury classification schemes of cervical spine trauma. “For example, flexion of the head may be produced by rotation of the head and neck, or may be the result of anteroinferior translation of the head relative to torso” (Melvin and Lighthall 2002).

The confusion is further compounded by the communication differences between injury, as shown in Figures 4 and 5 (Ommaya 1985). For example the term *extension* is defined in a clinical setting as a motion that brings the long axis of the distal portion of a joint parallel with the long axis of the proximal portion while from engineering perspective, it is referred to as *bending* (Melvin and Lighthall 2002).

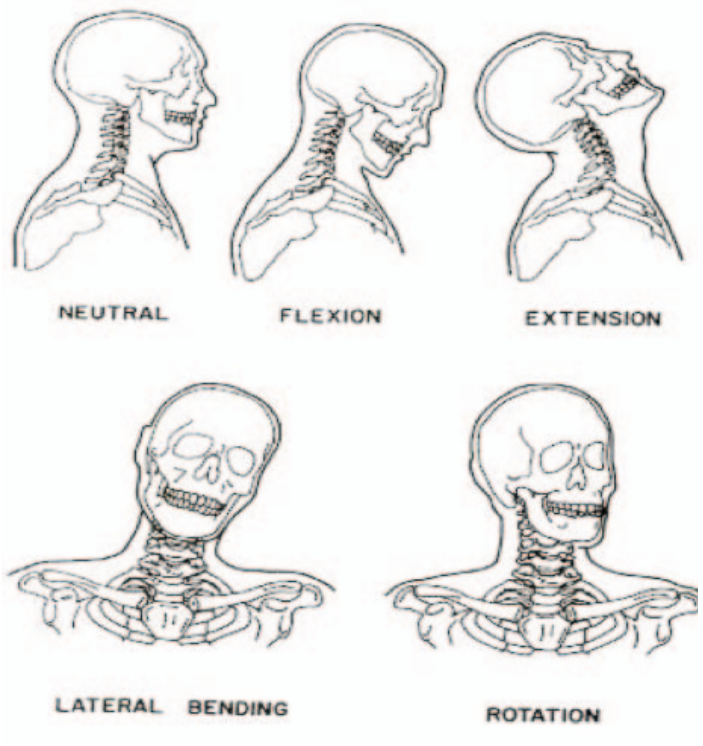


Figure 4 Anatomic description of head motion (*Source:* Melvin and Lighthall 2002)

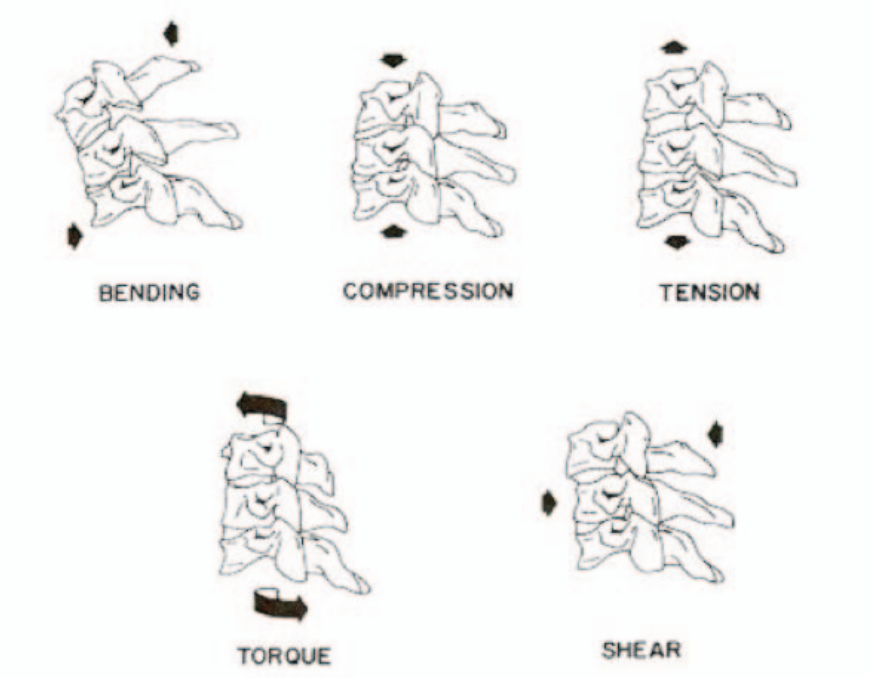


Figure 5 Engineering description of necks loading (*Source:* Ommaya 1985)

For clinical and epidemiological studies, it is possible that injury-causing forces acting on the spine may not be exactly known. In such cases, an injury may be assigned to multiple classes and categories of mechanism which may complicate the understanding. To simplify this issue, as shown in Table 5 (Melvin and Lighthall 2002), pure bending moments were added as classes of injury mechanism. This solution has resulted in a distinctive mapping of injuries to classes in Table 6 (Melvin and Lighthall 2002).

Table 5 Cervical spine injuries: mechanism of injury (*Source:* Melvin and Lighthall 2002)

Compression (vertical compression)	Jefferson fracture
	Multipart atlas fracture
	Vertebral body compression fracture
	Burst fracture
	Teardrop fracture
Compression-flexion	Vertebral body wedge compression fracture
	Hyperflexion sprain
	Unilateral facet dislocation
	Bilateral facet dislocation
	Teardrop fracture
Compression-extension	Posterior element fractures
	Odontoid fracture
	Teardrop fracture
Tension	Occipitoatlantal dislocation
	Atlantoaxial dislocation
	Odontoid fracture
	Basilar skull fracture
Tension-extension	Whiplash
	Odontoid fracture
	Anterior longitudinal ligament tears
	Disk rupture
	Horizontal vertebral body fracture
	Hangman's fracture
	Teardrop fracture
Tension-flexion	Bilateral facet dislocation
	Hyperflexion sprain
	Odontoid fracture
Torsion	Rotary atlantoaxial dislocation
Horizontal shear	Anterior and posterior atlantoaxial subluxation
	Odontoid fracture
	Transverse ligament rupture
Lateral bending	Nerve root avulsion
	Transverse process fracture
Other fractures	Clay shoveler's fracture

Table 6 A revised classifications of cervical spine injuries (*Source*: Melvin and Lighthall 2002)

Compression	Jefferson fracture
Multipart atlas fracture	Multipart vertebral body fracture
Compression-flexion	Burst fracture
	Wedge compression fracture
Compression-extension	Posterior element fractures
Tension	Occipitoatlantal dislocation
Tension-extension	Hangman's fracture
Flexion moment	Hyperflexion sprain
	Bilateral facet dislocation
	Unilateral facet dislocation
Extension moment	Hangman's fracture
	Anterior longitudinal ligamentous rupture
	Disk rupture
	Horizontal fracture of vertebral body
Torsion	Atlantoaxial rotary dislocation
	Atlantoaxial unilateral facet dislocation
Horizontal shear	Transverse ligament rupture
Multiple mechanisms	Odontoid fracture
	Teardrop fracture
	Clay shoveler's fracture

There were numerous experimental studies conducted to determine the limit on each item (Denny-Brown and Russell 1941; Nilsson *et al.* 1978; Gurdjian *et al.* 1955). However, all of the specifications were drafted based on the adult biomechanical limits. Since children anthropometric and biomechanical limits are unique compared to adult, there is a need to assess based on physical properties such as height and weight in order to develop an effective protection system.

3.2 Differences in Injury Patterns between Children and Adults

In a conference held in The Children's Hospital of Philadelphia (CHOP 2003), Duhaime and Margulies presented their study which revealed that in piglets; age has an effect on the response and recovery of the brain to focal impact and rotational load (Arbogast *et al.* 2003). If human follows the same principles and patterns, then it may be possible that brain damage increases with age when subjected to external loads. In other words, when significantly loaded, children's brains may suffer damage to a lesser degree when compared to adults' brains. If this hypothesis is acceptable, then children's helmet needs to be designed differently in order to be more effective in reducing brain injury.

In the same event, Ching highlighted that spine injuries stand out as the most severe in paediatric cervical spine (Arbogast *et al.* 2003). Since cervical spine injuries may be related to the impact to the heads, then this issue is relevant to helmet design and standards.

3.3 Anthropometric and Biomechanical Differences between Children and Adults

Children and adults have plenty of differences from these perspectives and the most prevalent would be the size, shape and biomechanics. From University of Michigan Transportation Research Institute (UMTRI) data presented in CHOP conference (2003), Klinich pointed that a child's head size undergoes rapid development from born till the age of 4 years old. The size reaches 90% of an adult's at 4 years old and 95% by age 12 (Arbogast *et al.* 2003). This finding is a relevant input for the design of children's helmet.

Additionally, the data also shows that at the same age of 4 and 12 years old, neck size for children is respectively 75% and 85% of adults' size and tend to be weaker with regards to muscle strength but has a higher level of stretch ability. These characteristics, as explained by Arbogast *et al.* (2003) during the CHOP (2003) conference, create a less restrictive forward motion for children's necks relative to adults' and give more freedom for the neck to bend. These attributes are some of the potential factors to be considered when determining helmet mass.

In the same conference, Becker stressed out the vast difference of children's facial structure in comparison to adults' heads, whereby the children's heads are shorter in vertical height. This distinct dissimilarity will cause adult-sized helmets to be unfit for children's heads. In addition, when the lowest part of the helmet's outer shell rested on the children's shoulders, there is a possibility that their heads will not fit and will barely in contact with the helmet's inner crown. Similarly, the chinstrap placement will have an effectiveness issue as well and, the helmet could obscure their visions when use (Arbogast *et al.* 2003).

With respect to brain and skull biomechanical properties, the variation between children and adult is apparently clear. It was explained in the CHOP conference (2003) by Margulies that a child's brain has greater water content which causes it to be stiffer than adult's (Arbogast *et al.* 2003). Additionally, it was also found in her research that the skull stiffness increases with age.

In addressing their baboon and animal model data in the conference, Ching and Pintar suggested that lower magnitude of force is required for the children's necks to fail in tension and compression, with respect to adults' necks. Their animal studies also suggest that neck stiffness increases with age.

All of the above experimental models suggested that children's anthropometric and biomechanical limits are different compared to adults'. The children's injury limits need to be assessed uniquely and not using adults' injury levels. Children's injury limits are more complicated because it needs to be assessed as a function of age. The age consideration is very important because children's anthropometric and biomechanical limits are different at every stage of age.

Hence, in order to design an effective head protection gear or helmet, the age factor needs to be considered seriously. To create a guide for injury levels, a stiffness scaling ratio was introduced by Ching to estimate the difference in injury limits of children (Table 7) (Arbogast *et al.* 2003).

Table 7 Stiffness scaling ratio (*Source:* Arbogast *et al.* 2003)

Age group (years)	UW (Baboon)			MCW (Goat) (Hiker 2002)		Mean (± IS.D.)
	Tension	Compression	Bending	Tension	Bending	
1	0.42	0.29	0.19	0.17	0.11	0.24 (±.12)
3	0.47	0.38	0.28	0.23	0.15	0.30 (±.13)
6	0.56	0.51	0.41	0.54	0.57	0.52(±.06)
12	0.71	0.72	0.64	0.85	0.62	0.71 (±.09
Adult	1.0	1.0	1.0	1.0	1.0	1.0

The scaling ratio was developed by University of Washington (UW) and the Medical College of Wisconsin (MCW) (Arbogast *et al.* 2003) and the analysis was presented by the group at Duke University (Table 8). If we accept that a reasonable maximum helmet weight for adults is 2 kg, then the maximum helmet weights for children could be obtained by applying scaling relationships to this adult value to yield corresponding child limits. Rather than using scaling parameters based on tolerance (failure) data, it would be more appropriate to apply functional metrics (e.g. stiffness, modulus, range of motion) instead. For example, the following table lists the scaling relationships between the adult (100 percent or 1.0) and various age groups based on measured stiffness properties in both the baboon and goat models.

Table 8 Helmet weight limit based on stiffness scaling ratio (*Source:* Arbogast *et al.* 2003)

Age group (years)	Lower limit (kg)	Higher limit (kg)
1	0.23	0.72
3	0.35	0.86
6	0.91	1.17
12	1.24	1.6
Adult	-	-

However this scaling methodology only considers the cervical injury. There might be other factors that need to be taken into account in order to create an optimal head protection for the head and cervical injury. For example, the limit or scaling factor of the skull and brain stiffness, including the helmet size scaling factor. In short, all these factors require considerations in creating a good standard for helmet design.

4.0 Malaysian Child Safety Helmet Study

To thoroughly evaluate the existing child helmet use and the extent of protective capability it offers, a search and review of relevant literatures was carried out. Simultaneously, an observational study of helmet use among schoolchildren in Klang Valley, Malaysia, was conducted together with physical performance test of randomly selected helmets in the market.

All the findings and evidences found in the literature review support the benefits of correct helmet use. Nevertheless, most of the studies concerned adult helmet wearing and do not address the differences in adult and child anthropometry (Arbogast *et al.* 2003). Therefore, further research shall be undertaken to establish children head protection needs in Malaysia.

4.1 Helmet Use Observational Study in Malaysia

The main intention of this study is to establish the prevalence of helmet use issues among primary schoolchildren in Malaysia of the age of seven to 12 years old. Moreover, motocycle is a very common transport to or from school. It is hypothesized that helmet use rate in urban schools is higher than in the suburb. Children above the age of 12 were not selected for this study since their head size could easily match and fit the helmet sizes addressed in almost all existing helmet standards.

4.1.1 Methodology

The Klang Valley was selected primarily due to its high number of registered motorcycles in the country (Road Transport Department 2008). The area is classified into urban and suburban. For reference, urban is defined as gazetted areas with their adjoining built-up areas which had a combined population of 10 000 or more (Mat *et al.* 2000). For suburban, the definition is a town or unincorporated developed area in close proximity to a city. Normally, suburbs are largely residential, and often dependent on the city for employment and support services; generally characterised by low-density development relative to the city (Mat *et al.* 2000). In reference to these, cities such as Petaling Jaya, Subang Jaya, Shah Alam and Klang are categorised as urban while Sepang, Kajang, Cheras, Seri Kembangan and Puchong as suburban zones. Eight schools were selected from each zone for observation and the specific locations were as reflected in Figure 6.

Since the study concerns children, primary schools are selected as it is relevant to children of ages between 6 and 12 years, and offers a higher chance of child size helmet usage compared to secondary schoolchildren with age of >12 and <18 years. For each zone, two primary schools were chosen and schools having morning and afternoon sessions were preferred. In total, 16 primary schools were selected for the observational study.

For data collection, the observation period was decided to be during school operation days and weekdays since these periods will record the highest number of observational opportunities. Schoolday changeover time between morning session and afternoon session was chosen because it encompassed most students attending each school. The changeover time usually lasts between one and 1.5 hours. The place of observation was ideally at the school main entrance.

All motorcycles with school going children passenger/s are considered, either with or without helmets, single or multiple passengers. The use of standard and non-standard helmets was recorded as well. All the observers were trained to identify and distinguish standard helmet and child helmet, non standard and toy or game helmet. To ensure minimal variations and consistent recordings, the same observers were deployed at all sites.

For data analysis, statistical package SPSS V11.5 for Windows was used and the level of significance was set at 0.05.

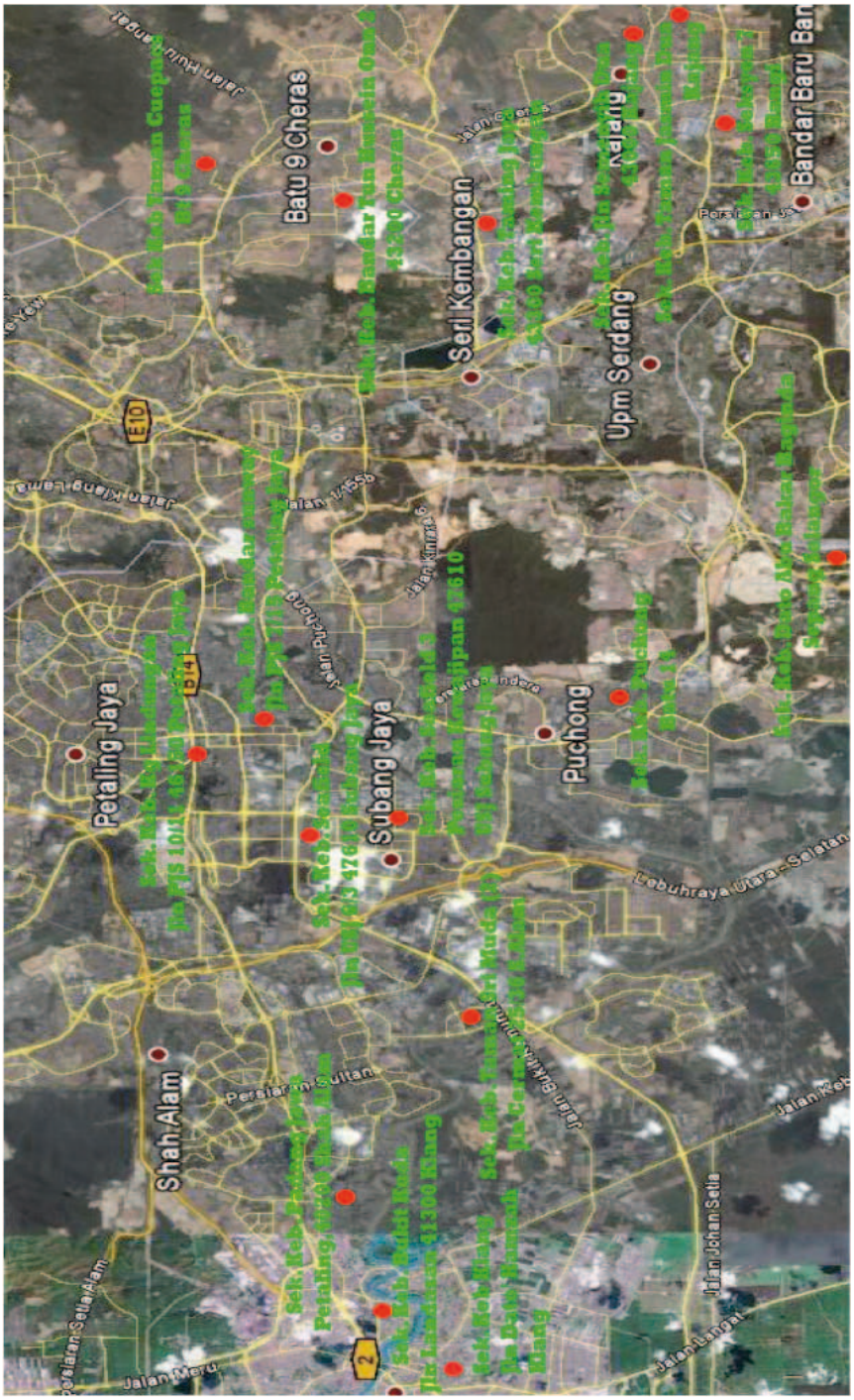


Figure 6 Location of schools for observational study in Klang Valley, Malaysia (*Source*: Googlemap)

4.1.2 Results and Analysis

It was hypothesized that the distribution of helmet use rate among schoolchildren in urban schools is higher than in non-urban. Using the Chi-Square test for Table 9, the calculated p value is < 0.001. Therefore, it is noted there is a significant association of school locations and helmet use. In other words, by percentage, it may be concluded that lower rate of helmet use could be associated to urban schools, but whether the relationship is a causal relationship remains undetermined.

Table 9 Observation results of helmet use in Klang Valley, Malaysia

	Use of helmet			
	Yes	Percentage, %	No	Percentage, %
Urban (N=309)	79	28.6	230	74.4
Suburban (N=493)	197	40.0	296	60.0

Based on the observation results in Tables 10 and 11, the average rate of non-use of helmets both in suburb and urban settings is relatively high, 60 and 74% respectively. For suburbs, across all schools the range of percentage of non-use is from 35 to 90%, while for urban it is from 50 to 95%. For both areas, one school under each zone recorded more than 90% non-use rate among the schoolchildren. It is noted that both schools are very close to rural districts and situated near low-cost housing areas but whether there is any correlation remains to be determined. Another issue of concern is the use of sub or non-standard helmet (not standard-compliant) which totalled 15% for suburb and 10% in urban schools. It is noted that a relatively very small percentage of children use standard-compliant child helmets, 4% for suburb and 2.6% for urban. Use of normal standard helmets stands at 20% and 12% for suburb and urban, correspondingly.

The result reflects the prevalent issue of non-use of helmets among schoolchildren when riding motorcycles in Klang Valley, Malaysia, both in suburb and urban settings. Furthermore, the rate of use of non-standard helmets is quite significant indicating possibly an easy accessibility, or speculatively could be due to unawareness and weak enforcement. It is also noted that quite a substantial number of children wear standard helmet which may potentially have some 'good fit' issue, either oversize or undersize. Such helmet may not appropriately fit the children head size, especially on the vertical side. Thus, the child's head may not get a good protection when subjected to significant impact forces.

Table 10 Helmet use rate, % (Suburb)

School	Use		Not use
	Standard	Non-standard	
Sek. Keb. A	39.7	25.0	35.3
Sek. Keb. B	25.5	12.7	61.8
Sek. Keb. C	16.4	20.0	63.6
Sek. Keb. D	34.9	8.4	56.6
Sek. Keb. E	14.3	5.4	80.4
Sek. Keb. F	4.6	4.6	90.8
Sek. Keb. G	28.4	23.9	47.7
Sek. Keb. H	34.8	21.7	43.5
Percentage, %	**25.0**	**15.0**	**60.0**

Table 11 Helmet use rate,% (Urban)

School	Use		Not use
	Standard	Non-standard	
Sek. Keb. I	3.2	1.1	95.7
Sek. Keb. J	26.8	14.3	58.9
Sek. Keb. K	21.0	5.3	73.7
Sek. Keb. L	12.4	18.8	68.8
Sek. Keb. M	0	23.1	76.9
Sek. Keb. N	16.0	12.0	72.0
Sek. Keb. O	20.7	5.8	73.5
Sek. Keb. P	27.8	22.2	50.0
Total	**15.2**	**10.4**	**74.4**

In addition to the quality and type of helmet concern, there are few other concerning issues requiring immediate attention. Firstly, there is an obvious practice of multiple child passengers riding on motorcycles, as reflected in Figure 7. Secondly, there are cases where the physical size of the children may not be suitable to ride as rear pillion passengers; the legs could not reach the footrest or the arms reach too short to firmly hold the rider in front, to provide the needed support. Another concern would be the habit of carrying passengers in front of the rider which have a tendency to distract the motorcyclist. However, scientifically, there is very little evidence to support these hypotheses and the area is understudied.

Figure 7 Multiple passengers on motorcycle

4.2 Availability and Design

In could be the case that most motorcyclist helmets currently available in Malaysia (size 50 to 62 cm) are designed for adult and children above five years of age. For children's size, this could be objectively substantiated by WHO data which indicated that for head growth standard worldwide, the 50th percentile head circumference for boy age two to five years is from 48.4 to 50.7 cm. The measurement for girls of the same age range would be from 47.3 to 49.9 cm (WHO Child Growth Standards).

It is speculated that the lack or limited size options may redirect users to opt for games or toy helmets originally intended for recreational use. The issue type could be related to the rate of 10% and 15% of non-standard helmet use in the observational study in Klang Valley. Furthermore, a price difference of approximately 20% may not be a deterrent to users and maybe perceived as insignificant. In addition, the toy/game helmet which is normally much lighter in mass than the standard helmet (approximately by 33 to 44%), may be better preferred by parents who are unaware of the associated risks of wearing inappropriate helmet. However, it is noted that such helmets are not standard compliant, thus have questionable performance for road use, as evident in the helmet performance test to be shown subsequently.

4.3 Child Helmet Performance Test

As a requirement in Road Transport Act 1987, all helmets for road use shall be certified to Helmet Standard, MS1:1996 before being made available to the market. To get an idea of child helmet performance in comparison to MS1:1996 Standard and adult helmet, a set of tests were conducted. It is hypothesized that the distribution of the head deceleration, g values in the impact attenuation test are independent of test conditions.

4.3.1 Methodology

A random survey of popular child helmet brands in the market was carried out and three top brands were selected. All samples were randomly purchased from motorcycle and accessories outlets in Kajang, Malaysia. All samples, except the game helmet, were in compliance of the Malaysian Standards MS1:1996 as indicated by the registered certification mark, as shown in Figure 8. The game and toy helmet were included in the test since they are widely used by children on motorcycles and could be easily sighted on the road.

Figure 8 Certification mark on standard helmet

For the test, all the samples were conditioned in accordance to MS1:1996 Standards requirement for ambience and hot temperature, water immersion, and artificial ageing (Malaysian Standards 1996) For ambience, the samples were exposed to a temperature of 25±5°C for minimum of four hours before the test and for hot, the conditioning temperature was 50±2°C for a minimum of four hours in a circulating air oven. Next, water immersion involves soaking the samples in water at a temperature of 25±2°C for fours hours as well. Lastly, the ageing process was done by exposing the samples to a radiation for 48 hours with a 125 watt xenon lamp at a distance of 25 cm, and then showered for four hours at ambient temperature. After conditioning, the samples underwent a retention system test, impact attenuation and penetration test. In the retention test, the helmet restraint system is statically loaded to a predetermined force and duration. For impact test, the helmet with headform is dropped from a predetermined height and the headform deceleration value in terms of gravitational force (g) was recorded. For penetration test, a conic striker was dropped from a predetermined height to simulate impact with a sharp object on the road.

4.3.2 Results and Analysis

All child helmet samples passed the impact, penetration and retention system tests, except game helmets which failed the retention system and penetration tests (Figure 9). Subsequently, for impact test, the head acceleration value in term of gravity or g for various conditioning mode was individually recorded, as summarised in Table 12.

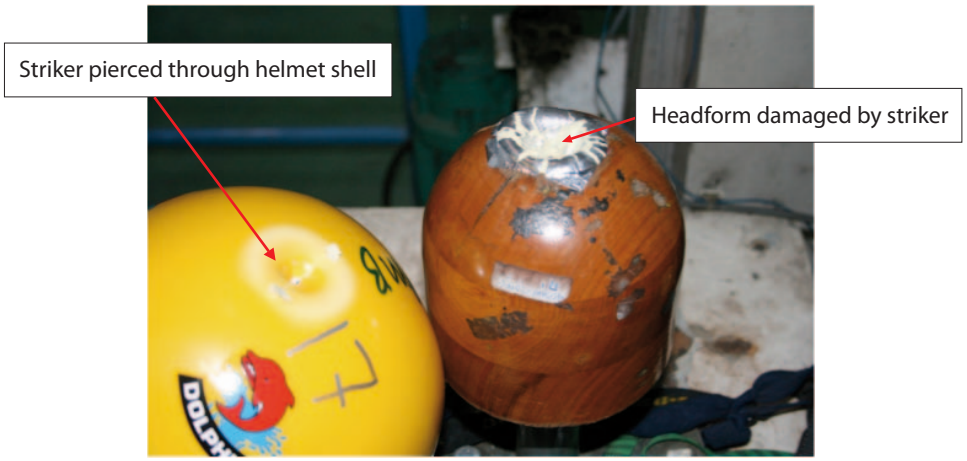


Figure 9 Games helmet failed the penetration test

Statistically, from Table 12, the chi-square test shows there is no relationship between helmet model (Standard compliant) and headform deceleration range (P=0.6, df=2). Similarly, test for Table 13 also indicates a P=0.6 (df=3), which means there is no significant association of test condition and headform deceleration range in impact test. A comparison of deceleration, g means between adult to child helmets in Table 14 illustrates that there is no significant relationship, where P=0.6.

Table 12 Association of helmet sample and headform deceleration (Child helmet)

Helmet model	Headform deceleration range, frequency		Total
	≤150 *g*	>150 *g*	
Sample 1	14	18	32
Sample 2	12	20	32
Sample 3	12	12	24
Total	38	50	88
Percentage, %	43.2	56.8	

Table 13 Association of test condition and headform deceleration (Helmet)

Test condition	Headform deceleration range, frequency		Total
	≤150 *g*	>150 *g*	
Ambient	9	15	24
Hot	7	9	16
Water immersion	13	11	24
Ageing	9	15	24
Total	38	50	88
Percentage, %	43.2	56.8	

Table 14 Mean comparison between child and adult helmets (Adult helmet, extracted from SIRIM QAS Int.)

	Child		Adult			
Variable	N	Mean (SD)	N	Mean (SD)	Mean difference	P-Value
Headform deceleration, *g*	88	165.03 (39.985)	160	167.57 (40.791)	2.54	0.638

In general, the distribution of child helmet head acceleration values *g* for the impact test is comparable to the adult standard-compliant helmets and no distinct variation was detected. In short, both helmet types demonstrated the same performance level. However, child injury tolerance level is relatively different from adult, thus equivalent value may mean differently or project dissimilar effects in each group. This is supported by a study by Anderson and Moore (1995) that summarised "children are more susceptible to permanent brain damage than adult when subjected to equivalent impact forces". Therefore, it may be essential to correlate these *g* values to HIC criterion and injury outcome to children in crash to ensure protection adequacy, which is currently not available from the established literatures. Oddy (1993) stressed that the "neurological shortfall (i.e. frontal lobe deficit – control of social interactions and interpersonal skills only needed at later years of development) as a result of head trauma may take longer period in child and may only be apparent at a later stage of development". In other words, in certain head trauma, the injury manifestation may take years to be noticeable. Therefore it is critical to thoroughly understand children injury tolerance in order to design a practical and safe head protection system.

In the result shown in Table 15, the majority (>70%) of impact values were between 100–200 *g* and none exceeded the 250 *g* (MS1 limit is 300 *g*). It was also observed that 64% of samples exhibited serious foam cracking after impact test, thus indicating helmet exposed to comparable impact energy in crash may possibly suffer similar risk of damage. In penetration test, the metal striker passed through the shell and created a punch mark on the impact foam in 36% of the samples. However no demonstrable contacts were made with the headform. Furthermore, the data also illustrated that 98% of the second impact *g* were higher (6~64 *g*) than first impact values. This trend was expected and all the values were within the specified range.

Table 15 Detailed result of impact test (Child helmet)

Deceleration range, *g*	Test condition				%
	Ambient T	Hot	Water immersion	Ageing	
<100 *g*	0	1	1	0	2.3
101–150	9	6	12	9	40.9
151–200	11	4	7	9	35.2
201–250	4	5	4	6	21.6
>250	0	0	0	0	0
Total	24	16	24	24	

The requirement for successive impact force (Malaysian Standards 1996) of equivalent magnitude applied to the same site may potentially initiate crack on the energy absorbing foams, if not to the shell. Additionally, the higher acceleration recorded in the second impact reflects a potential degradation of energy absorbing capability for helmets with significant pre crash or impact violation history. This phenomenon could be capitalized as part of the essential variables in determining a helmet's effective life and retention duration Measurements of the mass of standard child helmets showed that they range from 780 to 950 g. However, such mass may not be suitable for children below six years as revealed in Table 8. Therefore, further research is needed to understand the optimal helmet mass for children use.

With respect to game helmets, the failure in penetration and retention system test was very likely due to lower shell thickness of 1.5 mm and this provided the evidence that the helmet was not designed for such impact. Thus it is not suitable for motorcycle and road use.

5.0 Overall Discussion

From the perspective of legislation, it is clear that very few countries address regulations and policies regarding child helmet usage and other requirements for motorcycle pillion riding. Even though some inconsistency exists in the minimum age definition, the issue could be of low interest and maybe a rare

occurrence in developed countries. On the other hand, the issue of child passengers travelling on roads could be prominent in the middle and low income countries especially in South East Asian region (WHO 2008). Thus, an appropriate and socially and economically sensitive practical plan and policy on motorcyclist and passenger is essentially needed in order to improve children's safety when using the road on a motorcycle.

In view of child safety and injury prevention on the road especially in Malaysia, the determination of minimum age and physical requirement of children on motorcycle needs to be a precursor to any new establishment or amendments to the existing helmet standard and legislation. Since child injuries is largely a function of age and physical development, their anthropometrical constraints shall be considered in setting the age and physical requirement, for instance whether they can sit properly and safely as a rear pillion passenger. Other details such as child seating position either in front or behind the rider warrant some risk assessment as well.

Establishment of a suitable riding age and physical requirement limits will govern the determination of a more appropriate specifications and requirements of a child helmet, with potentially high benefit to cost ratio. The age limit shall mark the minimum injury tolerance a head protective system is required to meet. Should the helmet be accessible to a wider age range; there may be a requirement for it to be in compliance with toy safety regulations, such as CE 88/378/EEC, which at present, seems not a concern at all.

Performance test results indicated that general adult safety helmet and child helmet are highly comparable; however adult and children injury tolerance level are not. Hence, the mass and size range with respect to age need to be established and considered in developing children helmet specifications and performance requirements. Existing helmet standard size range does not sufficiently encompass the child passengers head size in Malaysia. Therefore such limitations may lead to children using 'ill-fitting' sizes, exposing them to unnecessary injury and health risk. To further enhance the existing standard, proper Head Injury Criterion (HIC) may be worthy of consideration. Helmet mass is another concern. Since there is little evidence to suggest that inappropriate mass contributes to neck injury, the area remains open for further exploration. An in-depth study of child injury and outcomes in motorcycles accidents may provide important leads.

Injury mechanisms are important factors to be considered in designing a helmet that provides an optimal protection system. Currently, helmet standards are drafted and derived based on the adult anthropometrical and bio-mechanical limit and these same standards are widely used for children helmets. This extension of existing standards is not appropriate due to the differences between adult and children injury limits. Several studies conducted previously determined and concluded that children anthropometric and bio-mechanical limits are relatively different compared to adult. The findings also show that children are uniquely very different because their injury limits vary with age and physical development.

Principally, using human models to determine the injury tolerance level will lead to an ethical issue. Almost all of the studies conducted to date used animals as models to duplicate human injury. Researchers and scientists are trying to correlate the injury limit of the animals to humans. However, there might be some differences between human and animal in terms of the injury limit and tolerance. Therefore such adoption needs to be carefully considered to avoid misinterpretation of the human injury tolerance.

To complement the advantage of proper helmet use, the existence of applicable legislations and appropriate enforcement efforts are equally essential. It was widely proven that effective enforcement could increase the rate of helmet use among motorcyclists and passengers as evidenced by a study in Vietnam (2006) which concluded that legislation coupled with enforcement have increased the rate of helmet use by motorcyclists on specified roads. It is also highlighted that the absence of legislation and enforcement resulted in low helmet use.

To suit child neck tolerance, it is perhaps possible to introduce a scaling factor for the helmet mass. In fact, the helmet mass versus age scale has been developed to cater to the differences in the child limits. This scaling can be further enhanced by considering brain and skull stiffness as well. Inclusion of these variables may enable helmet designers to design a helmet that provide optimal protection to the wearer.

In trying to determine the suitable helmet mass versus children age, another limitation will arise. The challenge is to discover light weight material with an acceptable cost that possesses similar or better properties relative to the current material in order to provide an equivalent and adequate protection to meet the injuries limit.

The observational study conducted in Klang Valley, Malaysia confirms the prevalence of non-use of helmets by primary schoolchildren. The association of low non-use rate in urban area warrants a detailed study to understand the underlying root causes.

A comparable pattern observed in the suburban settings indicate a possible systemic problem in delivering or accepting safety messages among the population, to appreciate any countermeasures or safety initiatives. If left unchecked, the trend may later be socially acceptable and may persist and be passed on to the next generation. However, it is important to note that since the study concentrated mainly on school areas in Klang Valley, the applicability of the pattern in highly travelled zones such as expressways and federal roads may need further examination. The study may be extended to rural areas as well. Correspondingly, appropriate efforts are highly needed to identify and tackle potential factors influencing high rate of non-use among children passengers. Additionally, other pertinent issues such as multiple passengers and passenger seating positions on motorcycles need to be addressed as well although this is not related to the focus of the study.

Further research opportunities remain to be explored such as looking into crash potential of motorcyclist in the presence of passengers in various riding configurations – front seated, rear seated, multiple passengers, children mechanism of head injury in motorcycle accident, and also mode of crash and injury relationship. Issue whether child helmet should be gendered require future investigation as well.

6.0 Recommendations

In an effort to make travelling safer for children on motorcycles, the following recommendations for consideration are proposed.

1. Evaluate helmet standards and incorporate children protection needs.
2. Conduct appropriate studies to identify and determine factors influencing non-use of helmet among schoolchildren, and carry out appropriate initiatives to improve.

3. Improve data collection system of motorcycle passenger and child passenger injuries in road traffic crash so that adequate data are available for factual based approach in designing intervention programmes.

In addition to the above, the recommendations below need to be considered as well.

i. Conduct a scientific study to establish child passenger physical characteristics and appropriate age for motorcycle riding and evaluate the needs and impacts to the community.

ii. Perform evaluation of safer seating position for children (front or rear of rider).

iii. Establish policy to regulate minimum passenger age requirement.

iv. Carry out advocacy and awareness and educational campaign among public on motorcycle safety.

v. Implement effective enforcement to regulate multiple passengers on motorcycles.

vi. Identify any possible policy improvements in motorcycle design to promote safer travel for children passengers.

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Appendices

Table A.1 Child helmets test result (Impact attenuation test)

Impact energy attenuation		(Maximum triaxial resultant 300 g)		Ambient temp.		Hot temp.		Water immersion		Ageing	
Sample 1	Fr	1st. Site :	1st. Impact	195	F	127	H	157	F	132	H
			2nd. Impact	230	F	139	H	188	F	172	H
	Rg	2nd. Site :	1st. Impact	155	F	96	H	173	F	123	H
			2nd. Impact	200	F	130	H	173	F	138	H
	Bk	3rd. Site :	1st. Impact	141	H	172	F	143	H	175	F
			2nd. Impact	160	H	234	F	138	H	196	F
	Lt	4th. Site :	1st. Impact	113	H	157	F	115	H	156	F
			2nd. Impact	128	H	190	F	128	H	197	F
Sample 2		1st. Site :	1st. Impact								
			2nd. Impact	198	F	121	H	198	F	140	H
		2nd. Site :	1st. Impact	221	F	157	H	231	F	187	H
			2nd. Impact	216	F	124	H	214	F	130	H
		3rd. Site :	1st. Impact	245	F	130	H	209	F	148	H
			2nd. Impact	162	H	209	F	140	H	207	F
		4th. Site :	1st. Impact	143	H	238	F	122	H	240	F
			2nd. Impact	140	H	203	F	124	H	230	F
Sample 3		1st. Site :	1st. Impact	158	H	218	F	138	H	245	F
			2nd. Impact								
		2nd. Site :	1st. Impact	187	F	n/a		139	F	126	H
			2nd. Impact	207	F			203	F	158	H
		3rd. Site :	1st. Impact	162	F			165	F	128	H
			2nd. Impact	193	F			168	F	140	H
		4th. Site :	1st. Impact	127	H			113	H	179	F
			2nd. Impact	122 109 118	H H H			104 92 122	H H H	229 174 201	F F F
Penetration Test				All passed		All passed		All passed		All passed	
Dolphin Games Helmet – Failed penetration test											
Impact not done due to risk of damage to triaxial accelerometer in headform											

Table A.2 Adult helmets test result (Impact attenuation test, courtesy of SIRIM QAS International, Shah Alam, Malaysia)

Impact energy attenuation	(Maximum triaxial resultant 300 g)		Ambient temp.		Hot temp.		Water immersion		Ageing	
Sample 1	1st. Site :	1st. Impact	148 g.	(F)	143 g.	(H)	111 g.	(F)	105 g.	(H)
		2nd. Impact	184 g.	(F)	169 g.	(H)	122 g.	(F)	129 g.	(H)
	2nd. Site :	1st. Impact	192 g.	(F)	102 g.	(H)	116 g.	(F)	110 g.	(H)
		2nd. Impact	235 g.	(F)	123 g.	(H)	131 g.	(F)	138 g.	(H)
	3rd. Site :	1st. Impact	135g.	(H)	170 g.	(F)	164g.	(H)	178g.	(F)
		2nd. Impact	147g.	(H)	192 g.	(F)	202g.	(H)	195 g.	(F)
	4th. Site :	1st. Impact	113g.	(H)	180 g.	(F)	179g.	(H)	175 g.	(F)
		2nd. Impact	121g.	(H)	227 g.	(F)	218g.	(H)	203 g.	(F)
Sample 2	1st. Site :	1st. Impact	221 g.	(F)	165 g.	(H)	153 g.	(F)	156 g.	(H)
		2nd. Impact	134 g.	(F)	201 g.	(H)	187 g.	(F)	165 g.	(H)
	2nd. Site :	1st. Impact	209 g.	(F)	148 g.	(H)	201 g.	(F)	155 g.	(H)
		2nd. Impact	230 g.	(F)	161 g.	(H)	228 g.	(F)	163 g.	(H)
	3rd. Site :	1st. Impact	165g.	(H)	205 g.	(F)	161g.	(H)	208 g.	(F)
		2nd. Impact	189g.	(H)	242 g.	(F)	182g.	(H)	239 g.	(F)
	4th. Site :	1st. Impact	182g.	(H)	207g.	(F)	194g.	(H)	202g.	(F)
		2nd. Impact	228g.	(H)	235g.	(F)	217g.	(H)	220g.	(F)
Sample 3	1st. Site :	1st. Impact	193 g.	(F)	121 g.	(H)	216 g.	(F)	110 g.	(H)
		2nd. Impact	202 g.	(F)	129 g.	(H)	224 g.	(F)	122 g.	(H)
	2nd. Site :	1st. Impact	187 g.	(F)	118 g.	(H)	223 g.	(F)	115 g.	(H)
		2nd. Impact	196 g.	(F)	128 g.	(H)	234 g.	(F)	123 g.	(H)
	3rd. Site :	1st. Impact	108 g.	(H)	201 g.	(F)	132 g.	(H)	191 g.	(F)
		2nd. Impact	117 g.	(H)	212 g.	(F)	144 g.	(H)	202 g.	(F)
	4th. Site :	1st. Impact	114 g.	(H)	198 g.	(F)	134 g.	(H)	184 g.	(F)
		2nd. Impact	122 g.	(H)	209 g.	(F)	146 g.	(H)	197 g.	(F)
Sample 4	1st. Site :	1st. Impact	186 g.	(F)	124 g.	(H)	216 g.	(F)	108 g.	(H)
		2nd. Impact	194 g.	(F)	132 g.	(H)	228 g.	(F)	118 g.	(H)
	2nd. Site :	1st. Impact	183 g.	(F)	122 g.	(H)	223 g.	(F)	114 g.	(H)
		2nd. Impact	196 g.	(F)	135 g.	(H)	234 g.	(F)	122 g.	(H)
	3rd. Site :	1st. Impact	104 g.	(H)	201 g.	(F)	135 g.	(H)	189 g.	(F)
		2nd. Impact	116 g.	(H)	209 g.	(F)	142 g.	(H)	197 g.	(F)
	4th. Site :	1st. Impact	110 g.	(H)	194 g.	(F)	131 g.	(H)	193 g.	(F)
		2nd. Impact	119 g.	(H)	207 g.	(F)	139 g.	(H)	202 g.	(F)
Sample 5	1st. Site :	1st. Impact	162 g.	(F)	120 g.	(H)	213 g.	(F)	112 g.	(H)
		2nd. Impact	176 g.	(F)	134 g.	(H)	226 g.	(F)	130 g.	(H)
	2nd. Site :	1st. Impact	180 g.	(F)	119 g.	(H)	217 g.	(F)	109 g.	(H)
		2nd. Impact	188 g.	(F)	127 g.	(H)	232 g.	(F)	117 g.	(H)
	3rd. Site :	1st. Impact	106 g.	(H)	185 g.	(F)	133 g.	(H)	189 g.	(F)
		2nd. Impact	114 g.	(H)	199 g.	(F)	145 g.	(H)	196 g.	(F)
	4th. Site :	1st. Impact	110 g.	(H)	193 g.	(F)	130 g.	(H)	194 g.	(F)
		2nd. Impact	118 g.	(H)	208 g.	(F)	142 g.	(H)	202 g.	(F)

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