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PUBLISHED PROJECT REPORT PPR697

Jersey Scrutiny review: Compulsory wearing of cycle helmets

J Carroll, N Kinnear, S Helman, D Hynd, and R Cuerden

Transport Research Laboratory
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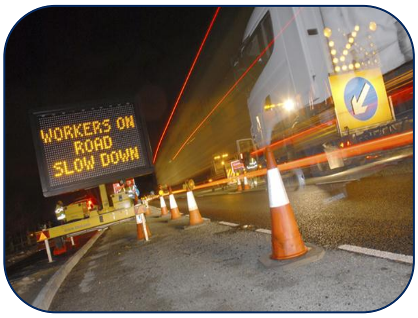


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Compulsory wearing of cycle helmets

Carroll J, Kinnear N, Helman S, Hynd D, Cuerden R

Prepared for: States Greffe, Scrutiny

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Quality approved:

William Donaldson
(Project Manager)

Richard Cuerden
(Technical Referee)

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Executive summary

The review

Mandatory cycle helmet legislation is being considered for introduction in Jersey. To help inform the policy decision, TRL has been asked to review the literature relating to the proposed legislation and its likely effects on cyclist injuries, and cycling activity. The review also covers the evidence on the effectiveness of helmets at the level of individual cyclists (i.e. the effectiveness of a helmet in reducing injury severity in a collision or crash) and other considerations relevant to the introduction of such legislation, including enforcement issues and wearing rates.

Evidence relating to these issues was gathered through a search of published literature in the Transport Research International Documentation, ScienceDirect, and PubMed databases. Literature gathered from the search was then graded for relevance (being related to cycle helmets, head injury safety, or the impact of helmet legislation on injury and cycling activity) and for scientific quality.

The effectiveness of helmets in the event of a collision

Although they cannot be expected to be protective in all collision types, the evidence is clear that helmets are effective at reducing injuries:

- Helmets dramatically reduce head injury metrics in tests with crash dummy head-forms and paediatric skulls.
- A large number of studies show that helmet wearers, if involved in a collision, suffer fewer head injuries than un-helmeted cyclists.

When considering the situations in which helmets will be most effective it should be noted that these tend to be the types of collision which are most common among cyclists (non-vehicle collisions such as falls). It should also be noted that most studies focus on the prevention of head injuries; there may be benefits associated with reducing the severity of an injury, e.g. from severe to moderate, that are not accounted for in these studies.

The impact of helmet legislation on injuries

The evidence as a whole suggests that mandatory cycle helmet legislation is associated with a reduction in reported head injuries (including injuries to the face and neck), for cyclists of all ages.

The impact of helmet legislation on cycling activity

The evidence on the impact of helmet legislation on cycling activity does not provide a definitive answer, although the weight of evidence suggests that if legislation has any effect on the amount of cycling, it tends to be a small and short-term reduction in child cycling. The very large reductions often sometimes cited by opponents of cycle helmet legislation, which have been based on early analyses of observations of cycling rates in Australia in the 1990s, have not been observed elsewhere.

Conclusions

On the basis of the evidence reviewed, we draw the following conclusions:

1. Legislation requiring the wearing of cycle helmets in Jersey can be expected to have a beneficial effect on the injury rates of those impacted by the legislation, especially in collisions that do not involve motor vehicles.
2. Such legislation seems unlikely to have a major impact on cycling activity in Jersey.

Other considerations

The authorities in Jersey will clearly be considering practical constraints to the legislation if it is introduced, including how enforcement will be handled, and how support might be put into place for cycling tourists and those who may be less able to procure a helmet for financial reasons. The evidence reviewed suggests that strong enforcement is likely to achieve higher wearing rates, but also that legislation alone is effective at increasing wearing rates.

As with any road safety law (should legislation be adopted) we recommend that attention is paid to ensuring that the public is aware of the legislation, and that publicity makes it clear that the new law is based on evidence and is designed to make cycling – an already healthy activity - a safer activity. In addition, Jersey authorities should continue to promote improvements to cycle safety in other ways if they wish to encourage more cycling; for example the enforcement of vehicle speeds, and attention to improving and advertising the existing cycling infrastructure should be continued.

Finally, we recommend that wearing rates and cycling activity rates are both monitored both before and after the legislation is enacted, in an appropriate and scientifically controlled evaluation framework that permits before-and-after comparisons of these outcomes (as well as injury rates). Such monitoring should also include surveys of attitudes towards cycling and cycle helmets. Such monitoring and evaluation will enable firm conclusions to be drawn on the effects of the legislation, permitting on-going improvements to cycling and cycling safety provision Jersey.

Table of Contents

Executive summary i

1 General approach 5

1.1 Topics to be considered 5

1.2 Outcomes 5

1.3 Report structure 6

2 Literature search 7

2.1 Introduction 7

2.2 Searching of published literature 7

2.3 Grading of literature 7

2.4 Timeliness 7

3 Influence of a cycle helmet on head injury outcome 9

3.1 Cycle helmet design and testing 9

3.1.1 Principles of cycle helmet design 9

3.1.2 Cycle helmet standards 10

3.1.3 Proof of performance 11

3.2 Characteristics of pedal cycle casualties 14

3.3 Features expected to affect helmet effectiveness 22

3.4 Summary of helmet effectiveness 24

4 The impact of cycle helmet legislation on injury outcomes 27

4.1 Helmet wearing rates 27

4.2 Compulsory helmet wearing legislation and injury 29

5 The impact of cycle helmet legislation on cycling activity 32

5.1 Health costs and benefits 33

5.2 Attitudes and barriers to cycling 34

5.3 Summary 35

6 Jersey scrutiny review – local evidence 36

6.1 Background 36

6.2 Road safety in Jersey and Infrastructure 37

6.3 Scrutiny Panel 37

6.4 Enforcement 37

6.5 Summary of the Jersey experience 40

7 Summary and conclusions 42

References 44

1 General approach

This review aims to summarise the evidence on legislation that requires the wearing of a cycle helmet, relating to three topics to be considered. The first and second of these areas are focused on outcomes that are relevant to public health; the third area focuses on those pragmatic issues related to how one might go about introducing such legislation. More detail on our approach is given in Section 1.1 and 1.2.

1.1 Topics to be considered

After considering the evidence for the effectiveness of cycle helmets in the event of a crash (so as to understand the key injury prevention mechanism involved, and evidence for them) we then summarise the evidence on whether injuries from cycle collisions change after the introduction of legislation requiring the wearing of cycle helmets. Then we summarise the evidence on whether legislation requiring the wearing of cycle helmets is associated with any change in the amount of cycling.

That the injury burden arising from cycling is relevant to public health is unarguable. The amount of cycling being undertaken in a given jurisdiction is, we assume, also of some relevance to public health. The basis of this assumption is that cycling has been demonstrated to decrease mortality rates in men and women, even after other factors such as leisure exercise, smoking and Body Mass Index are taken into account (Andersen et al., 2000). We therefore make the assumption that cycling as an activity (separated from any injury burden) is desirable.

The third area summarised in our review concerns practicalities associated with implementation of such legislation, and other issues that require consideration within the wider social context. These include issues such as how to ensure that the legislation is correctly and sufficiently enforced, that appropriate cycling infrastructure is provided, whether people may change their behaviour by virtue of wearing a helmet ('behavioural adaptation') and how to go about monitoring and evaluating the short, medium and long term changes in the outcomes of interest in the specific jurisdiction under investigation.

1.2 Outcomes

Our approach prioritises the primary outcomes measures of injury and cycling activity, over proxy measures such as public attitudes towards cycling or to helmets. The main reason for this is that proxy or 'surrogate' measures may not relate in obvious ways to the primary outcomes of interest; effects of legislation on proxy measures may not translate into changes on the primary outcomes. This is a finding that has been noted in several other areas of investigation associated with public health and injury or disease outcomes (see for example BMJ, 2011). For the reasons outlined in Section 1.1 we assume that less injury and more cycling are both desirable outcome measures, and therefore we seek to summarise evidence related to these.

In all cases however, when we consider the evidence of an effect of cycle helmet legislation on injury and cycling outcomes, we also consider the theoretically plausible mechanisms by which such effects may come about. Other considerations such as helmet wearing rates, enforcement, infrastructure, and behavioural adaptation are included therefore in our consideration of outcomes by virtue of the fact that they may provide some detail on the mechanisms by which effects on the primary outcomes may accrue. For example, if our review found that injury benefits were found only in those jurisdictions in which legislation has been enforced reliably, or only where wearing rates were raised appreciably, those considering the introduction of such legislation would need to know this.

1.3 Report structure

The remainder of this report is structured as follows.

Section 2 outlines the approach taken in the literature review, including the search terms and databases used.

Section 3 discusses the evidence on the effectiveness of helmets at reducing injury severity in the event of a crash. Although the focus of this review is on legislation, the mechanisms by which helmets are designed to work are important for the debate.

Section 4 summarises the evidence relating to the effects of cycle helmet legislation on injury outcomes.

Section 5 summarises the evidence relating to the effects of cycle helmet legislation on cycling activity.

Section 6 outlines the evidence relevant to Jersey and summarises the pertinent information specific for Jersey.

Section 7 draws overall conclusions and makes recommendations.

2 Literature search

2.1 Introduction

A literature review was undertaken to identify the recent evidence base about collisions involving cyclists. This included evidence relating to:

- The effectiveness of cycle helmets for the individual and the population;
- The effect of helmet legislation on head injury rates for cyclists;
- The effect of helmet legislation on cycling rates;
- Other factors such as the enforcement approaches in jurisdictions with helmet laws and evaluation of any changes made.

2.2 Searching of published literature

Published literature was searched using the following methods:

- Searches using databases held by TRL;
- Web-based search tools (e.g. Google Scholar);

The following databases were interrogated by TRL:

- TRID – Transport Research International Documentation is an integrated database that combines the records from TRB's Transportation Research Information Services (TRIS) Database and the OECD's Joint Transport Research Centre's International Transport Research Documentation (ITRD) Database. TRID provides access to more than one million records of transportation research worldwide;
- ScienceDirect - an online resource focussing on scientific, technical and medical information with almost 9 million articles; and
- PubMed – reference database containing several million records covering life sciences and biomedical research.

The search terms used in the study are shown in Table 2.1 overleaf.

2.3 Grading of literature

The grading of literature found in the searches was undertaken to select only those articles which were directly relevant to cycle helmets, head injury safety, and the impact of legislation on injury and cycling activity. For primary sources of information, they also had to be peer reviewed.

2.4 Timeliness

Timeliness refers to when the article was published. This was based on analysis of the abstract's year of publication, as opposed to the date of any data referred to in the article's title or abstract text.

For this search, articles were considered if they were published after 2008. The reason for this is that the previous TRL review (Hynd et al., 2009) of the literature included articles up to this date.

Table 2.1: Literature search terms used in the present review

Types AND	**Equipment** AND	**Legislation** OR	**Safety** OR	**Behaviour** OR	**Enforcement**
Bicycle	Helmet*	Legislat*	Safety	Attitude*	Enforce*
Cycle	Head protection	Compulsory	Casualty	Behav*	Flout
Bike		Law	Injur*	Educat*	Disobey
Cyclist		Rate*	KSI	Confidence	Comply
Cycling		Mandatory	Death	Perception	Compliance
			Fatal*	Perceive	
			Accident*	Wear*	
			Incident*	Proportion of cycl*	
			Collision*	Number of cycl*	
			Crash*		
			Severit*		
			Contributory		

3 Influence of a cycle helmet on head injury outcome

3.1 Cycle helmet design and testing

The primary function of a cycle helmet is to attenuate the energy transferred to the cranium and brain on impact by distributing and absorbing this energy. The efficacy of this attenuation is the subject of certain tests within helmet standards and also in research testing. Basic information concerning the helmet design principles, test standards and laboratory test results are described in the following three sub-sections.

3.1.1 Principles of cycle helmet design

Generally, protective helmets consist of a shell and an energy absorbing layer. Modern cycle helmets typically have a micro-shell, usually between 0.3 and 0.8 mm thick, that is often bonded to the liner material during the manufacturing process. The micro-shell liner provides little rigidity or load distribution, but may help to maintain helmet integrity in an impact, which may be particularly important if a second impact occurs in the same accident. A hard shell is likely to distribute loading better in a localised loading condition, and would be expected to be better than a micro-shell in protecting against penetration of sharp objects.

In both hard-shell and micro-shell helmets, the liner will absorb a proportion of the impact energy and will distribute the impact loading over a wider area of the head (particularly in impacts with a relatively flat surface). Both of these features will reduce the risk of cranium fracture (through reducing the localised strain on the cranium) and the risk of skull fracture and brain injury (through reducing translational acceleration of the head). The proportion of impact energy absorbed will depend on the design of the helmet, the impact tests that the helmet has been designed to meet and the type of surface impacted.

In the process of absorbing a proportion of the energy of an impact, the structure of the helmet is usually damaged. This is an important characteristic of helmets: if the liner material was elastic the impact energy that was initially absorbed would be returned to the head later in the impact, thereby greatly reducing the effectiveness of the padding. Liner materials are therefore primarily plastic in their deformation characteristics. By changing the material used as the liner, it is theoretically possible to tune the head protection properties for a particular impact condition of interest (Asiminei et al., 2009). However, the extent to which this is done by helmet manufacturers also depends upon material availability and cost.

Helmet fit and retention are also considered to be important, because an improperly fitting helmet may not provide the designed impact absorption, and a helmet that is dislodged in an impact may not provide any protection at all. In addition to these considerations, ventilation and aesthetics are considered important to the comfort and user acceptability of helmets. Furthermore, cycle helmets for use on the roadway are usually designed to ensure that the vision and hearing of the rider are not compromised.

The most pragmatic helmet designs balance the need for good impact performance in the event of a fall or collision, with the need to be acceptable, practicable and comfortable when used.

Based on a consideration of head injury biomechanics and the mechanics of helmeted head impacts, cycle helmets would be expected to be effective in mitigating a proportion of serious head injuries:

- The risk of cranium fractures would be markedly reduced, particularly in impacts with flat surfaces, because the helmet liner material will reduce and distribute the impact forces;
- The risk of focal brain injuries would be markedly reduced, particularly in impacts with flat surfaces, because the helmet liner will reduce the peak head acceleration and because the reduced cranium fracture risk would reduce the risk of secondary brain injuries from displaced fragments of the fractured cranium.
- The risk of diffuse brain injuries (such as concussion and diffuse axonal injury) would be reduced in proportion to the marked reduction in impact forces. Additional reduction of the risk of diffuse brain injuries could accrue if the coefficient of friction of the impact was controlled, for instance by adding a suitable test to the cycle helmet standards. Helmets that incorporate an internal shear layer to control and minimise the coefficient of friction have been available for motorcycling and equestrian activities for several years and have recently become available for cycling.

3.1.2 Cycle helmet standards

Hynd et al. (2009) reported on cycle helmet testing and made the following observations. In most jurisdictions, cycle helmets are tested to ensure a minimum level of performance for a range of criteria that affect safety. Typically these include:

- construction requirements;
- impact test requirements;
- retention system (strap) strength and helmet stability;
- definition of the minimum area of the head covered by the helmet; and
- definition of a minimum field of view (to ensure that the helmet does not impede the vision of the wearer).

Most cycle helmet standards around the world define similar types of impact test, but the impact severity, pass/fail criteria and number of tests per helmet vary in different standards. This means that helmets certified to one standard may not pass the requirements of another. In addition, cycle helmet standards have changed over time and so current helmets in the UK may be quite different to those sold in other regions or in previous decades. The results of real-world cycle helmet effectiveness studies must be considered in the context of these regional and temporal differences in cycle helmet standards.

It was found that cycle helmets designed to the Standards currently used in the UK (EN 1078 for child and adult helmets and EN 1080 for younger child helmets) would, based on biomechanical principals, be expected to be effective in many cycle accident conditions. This effectiveness would depend on a range of factors, such as the type of accident (e.g. a fall from a cycle or a collision with another vehicle), the stature and injury tolerance of the rider, and the shape and stiffness of the object struck by the head (e.g. a flat road surface, a kerb, or a deformable car bonnet).

3.1.3 Proof of performance

Cripton et al. (2014) characterised the ability of one typical contemporary bicycle helmet to reduce the severity of a head impact compared with not wearing a helmet. This was determined through matched laboratory impact tests with a helmeted and unhelmeted anthropometric headform (a Hybrid III dummy head, which includes a representation of the scalp). The testing used a range of drop heights between 0.5 m and 3.0 m.

In 2 m (6.3 m/s) drops the helmet reduced peak accelerations from 824 *g* (unhelmeted) to 181 *g* (helmeted) (see Figure 3-1) and HIC_{15} was reduced from 9,667 (unhelmeted) to 1,250 (helmeted). At impact speeds of 5.4 m/s (1.5 m drop) and 6.3 m/s (2.0 m drop), bicycle helmets changed the probability of severe brain injury from extremely likely (99.9% risk at both 5.4 and 6.3 m/s) to unlikely (9.3% and 30.6% risk at 1.5 m and 2.0 m drops respectively) (see Figure 3-2). These findings are also supported by the helmeted dummy head to PMHS head test comparison made by McIntosh et al. (2013). Evaluation of the 3 m drops demonstrated that helmets only offer a finite amount of protection. At impact speeds of this velocity the energy management capability of the helmet is saturated and the EPS liner bottomed out. If the energy absorbing potential of the helmet is greatly exceeded, it may no longer offer a significant advantage over the bare head condition. However, the 7.7 m/s impact speed in this case is unlikely to be representative of most real-world bicycle impacts.

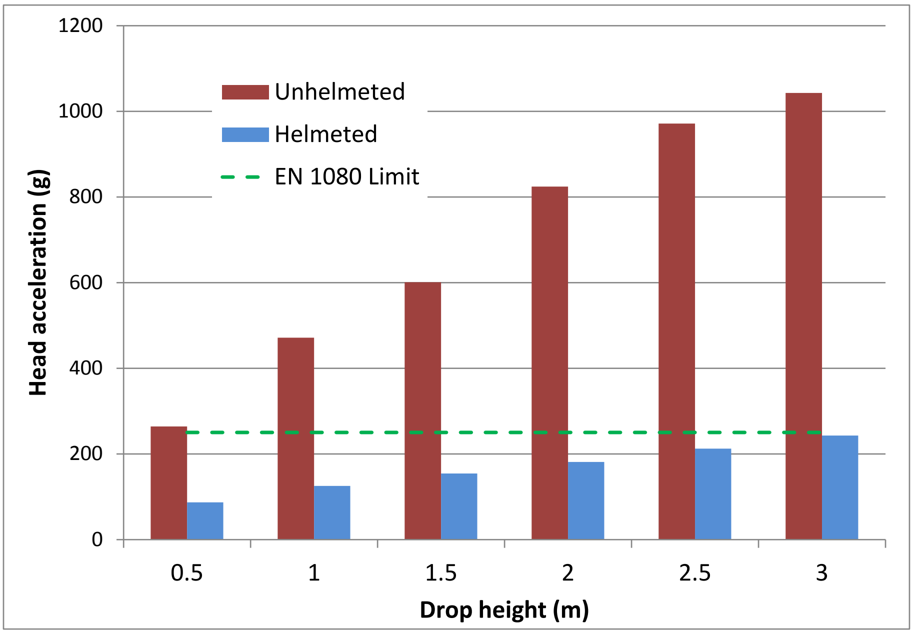


Figure 3-1: Head acceleration for unhelmeted and helmeted headforms (based on Cripton et al., 2014)

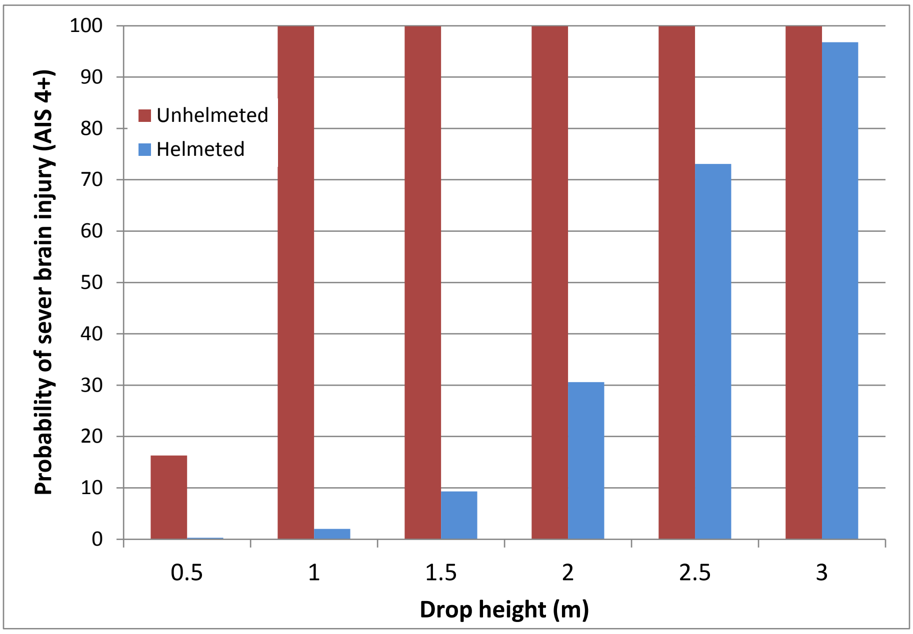


Figure 3-2: Predicted risk of severe brain injury for unhelmeted and helmeted headforms (based on Cripton et al., 2014)

An impact test stand was fabricated by Mattei et al*.* (2012) to assess the efficacy of a bicycle helmet in the attenuation of impact energy on a human skull. They used paediatric PMHS (post-mortem human subject) skulls obtained from donors ranging from 8 to 10 years of age. Each skull was fitted with a commercially available representative children's bicycle helmet (Bell Fraction). The skull and helmet assembly was then released into free fall from selected heights ranging from 6 to 48 inches (15 to 122 cm) onto a flat steel impact anvil. This procedure was repeated with an unhelmeted skull, but only test data for unhelmeted skulls subjected to 6 inch and 9 inch drops were used for comparative purposes.

The mean maximum resultant acceleration of the helmeted skull from the 6 inch drops was 57 ± 8 *g*, and the corresponding mean maximum resultant acceleration for the unhelmeted skull at the same drop height was found to be 440 ± 79 *g* (both values expressed as the mean ± SD). From these data it could be concluded that, at a drop height of 6 inches, the unhelmeted skull experienced acceleration 7.7 times greater than the helmeted skull at the same height. The head accelerations for helmeted and unhelmeted impacts are shown in Figure 3-3. NB: The arrow on the unhelmeted result at 9 inch drop height indicates that the accelerometer reached its maximum measurement range and therefore the peak acceleration was likely to be higher than the value shown; also, values for the helmeted tests at 12-48 inches are not given in the paper and have been estimated from a graph shown in the paper. It can also be seen that even at a drop height of 48" (122 cm), the head acceleration in the helmeted test is only three-quarters of that measured in the unhelmeted test at a drop height of 6" (15 cm).

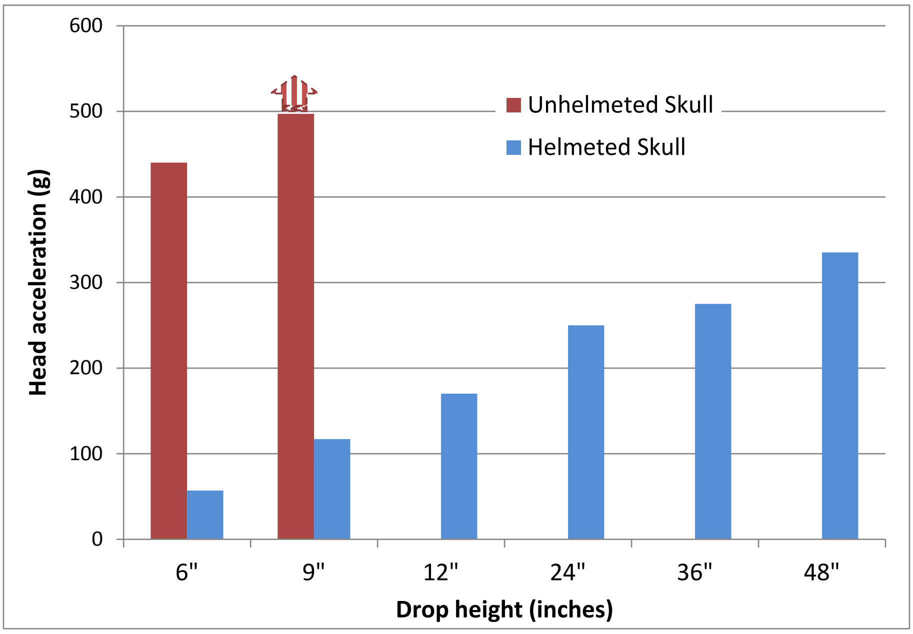
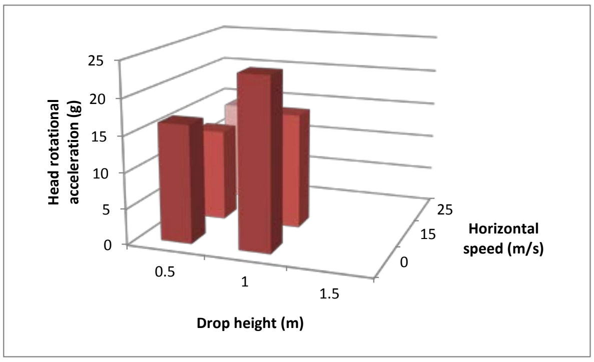


Figure 3-3: Head acceleration for unhelmeted and helmeted paediatric skulls (based on Mattei et al., 2012)

In the study by McIntosh et al. (2013), the head responses in oblique impacts were analysed and compared against helmet use, impact location, impact severity, and helmet adjustment. A series of laboratory tests was undertaken using an oblique impact rig. This included a drop assembly with a Hybrid III dummy head and neck. The head struck a horizontally moving striker plate. Head linear and angular acceleration and striker plate force were measured. The results showed that helmets reduce peak linear and angular head accelerations (see Figure 3-4), HIC_{15}, and force. The results showed that in all unhelmeted tests it would be anticipated that the unprotected bicyclist would suffer at least concussion or a mild traumatic brain injury (mTBI) in the least severe impact and have a greater than 30 percent chance of suffering a serious skull or brain injury with impacts of greater severity.



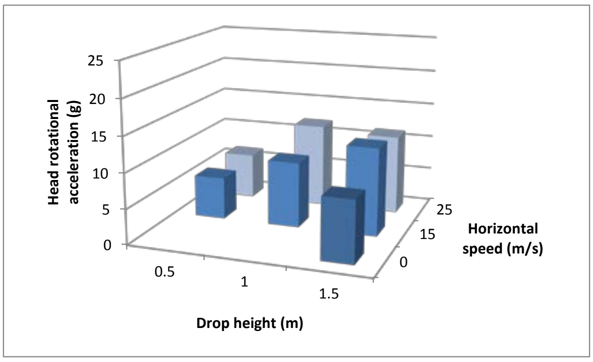


Figure 3-4: Head rotational acceleration (maximum in any orientation) for unhelmeted and helmeted headforms (based on McIntosh et al., 2013)

For helmeted impacts there was an identifiable risk of concussion/mTBI related to the maximum resultant linear, centre of mass, headform acceleration and HIC_{15} for impacts equivalent to a drop height of at least 1 m and a horizontal speed from 0 to 25 km/h. Due to the mean HIC_{15} of 730 in the 1.5 m drop and 25 km/h horizontal speed occipital impacts, there was a risk of serious skull and brain injury. There was an identifiable risk of mTBI and serious brain injury related to angular accelerations. The study confirmed that bicycle helmets certified to a national standard are effective from a biomechanical perspective in reducing linear and angular head accelerations, as well as impact force. It has been used to counter claims that helmets increase angular acceleration and related injury (Olivier et al., 2013c).

Whilst the work of McIntosh shows that in certain impact conditions, the wearing of a helmet will reduce the linear and rotational acceleration of the head upon impact, it cannot show that this will be the case in every conceivable scenario. At very high severities, the helmet liner may compress completely (though it should still be effective in distributing force and absorbing a proportion of the impact energy). Also, whilst we do not expect helmet projections to be able to add injurious rotations to head kinematics, the true rotational behaviour of a bare human head in oblique impacts is not known. Therefore, whilst the indications are that a helmet will reduce angular acceleration for a head, we cannot be sure that the addition of a helmet doesn't increase the tendency for rotational acceleration over the unhelmeted head in some oblique contacts.

For further assessment of the protective effects conferred by a bicycle helmet, a compression test was developed by Mattei et al. (2012). This test measured the ability of the helmet to shield a skull from damage in a crush situation. The test procedure consisted of the individual placement of bicycle helmets on their sides on the platform and compressing them with the pneumatic cylinder while recording their load versus time parameters with the data acquisition system. This procedure was repeated for PMHS skulls fitted with a bicycle helmet and without. Maximum tolerated loads for each scenario were then evaluated.

Evaluation of the helmet-only compression data showed initial cracking that occurred in the range of 100–200 lbf. The average cracking force was found to be 140 lbf. The skull and helmet assembly could not be crushed in the compression stand even under the maximum force experienced by the load cell (470 lbf). It could be seen during testing, however, that the helmets without the skull cracked at approximately 190 lbf. This is consistent with data from the compression testing provided by the manufacturer of the selected helmet used during the tests. The unhelmeted skull underwent catastrophic failure during testing, experiencing a maximum load of 520 lbf.

It was previously thought that bicycle helmets would not confer much benefit to the wearer in accident events where the head was compressed. The testing of Mattei et al. shows that there may indeed be benefit under certain compressive loading circumstances.

3.2 Characteristics of pedal cycle casualties

Pedal cycle related incidents have marginally increased in the last year on Jersey, but are still lower than the 10 year average by 14% (Child Accident Prevention Jersey, 2013). There were 115 bicycle related unintentional injuries, the annual average since 2004 being 131. The most common injury location was to the upper and lower limbs and head/face (Table 3-1). Injuries to the head were seen more in children aged between 5 and 10 years. However, children attending the Jersey Emergency Department with a bicycle related injury were more likely to be aged 10 or 12 years and above. 23% of children seen because of a bicycle related unintentional injury required further hospital treatment after their first ED attendance. 5% (6) of children attending with a bicycle related unintentional injury were admitted into hospital; 1 limb injury, 4 head injuries and 1 laceration.

Of the 115 children attending the Jersey Emergency Department because of a bicycle related unintentional injury;

- 18% (21/115) stated they had not worn a helmet
- 55%(63/115) had no helmet status recorded
- 27% (31/115) stated they had worn a helmet

Although there is no information available on helmet wearing and the likelihood of injuries being sustained.

Table 3-1: Unintentional bicycle-related injuries seen in the Jersey Emergency Department in recent years (Child Accident Prevention Jersey, 2013)

Injury Site	2013 (%)	2012 (%)	2011 (%)	2010 (%)
Head/face injury	22	19	21	31
Upper limb	50	47	43	43
Lower limb	22	23	24	20
Abdominal/back	2	3	4	0
Multiple injury excluding head	4	8	8	6

A variety of events can lead to a bicyclist being injured in an accident. Three simple categories that can be considered are single vehicle accidents where the cyclist falls or rides into an inanimate object, collisions with another vehicle of similar size (e.g. bicycle-to-bicycle accidents) and collisions with motorised vehicles, such as cars and heavier vehicles. Each of these types of incident can be expected to have a different taxonomy of implications and injuries for the cyclist. The head protection afforded by helmets might be more or less effective depending on the collision type.

Boufous et al. (2011) examined police crash records as well as hospital data from Victoria, Australia, over a 5-year period (2004–2008). Among 6,432 cyclist crashes reported to police in Victoria between 2004 and 2008, 2.5 percent involved children aged 0–9 years, 17.4 percent involved adolescents aged 10–19 years, and 80.1 percent involved adults aged 20 years and older. During the same period there were 7,868 cyclist hospitalisations, with half of the admissions resulting from traffic crashes. Though proportions of each age group for cyclist hospital admissions as a result of traffic crashes were similar to those found in police crash data, the proportions of children (16.7%) and adolescents (41.7%) were much higher for cyclist hospitalisations resulting from non-traffic crashes.

An examination of road user movements showed that the most frequent type of police-reported crashes involving children occurred when cyclists were struck by other vehicles emerging from driveways (41.6%) followed by those when cyclists emerged off a footpath into the path of a vehicle (32.3%). These crashes were also the most common crash types in adolescents. This is in contrast to crashes involving adult cyclists, for whom the most frequent types were right-through crashes (turning right across oncoming traffic; 12.6%), cross-traffic crashes (for instance at a four-way interchange; 9.9%), and in which the cyclists struck the door of a parked/stationary vehicle (9.1%).

From this study it can be seen that as opposed to adult cyclists, non-traffic incidents (single bicycle falls, etc.) are likely to be the primary type of collision to consider when thinking about the dominant circumstances in which a helmet needs to protect the head of a child cyclist. This was also true in Israel, where falling from the bicycle (65.4 %), being struck by a motor vehicle (31.6 %), or riding as a passenger on a bicycle in the company of an adult (3.0 %) were the main trauma mechanisms for bicycle-related injuries in children up to 18 years of age (Klin et al., 2009). Similarly in the United Arab Emirates (Hefny et al., 2012), the most common mechanism of injury for UAE nationals was falling from a bicycle (73.7 %) and for all nationals under the age of 15 (65.5. %). Kiss et al. (2010) also reported that a fall from a bicycle was the most frequent mechanism of injury in a study of 1,803 bicycle-related child (under 18 years of age) casualties treated in Hungary.

Kiss et al. describe differences observed with the injury occurring either in a village, midsize or large town. They also comment on the fact that of the children 31.8 % had long-term physical and 15.9 % had psychological disabilities after the injury.

In the study by Airaksinen et al. (2010) data from Finland of bicycle crashes leading to medical attendance in acute hospital or to death were analysed. The number of bicycle crashes in the hospital data was at least fourfold compared to the number found in the official police statistics. Again it was reported that the majority of the bicycle crashes considered occurred when the injured person was alone. Over one third of all cyclists' injuries were head injuries. Although in this sample of all ages, crashes were often alcohol-related (31 %). Only 13% of the injured cyclists wore a helmet and 15% of those who wore a helmet sustained a head injury and, correspondingly, 43% of those who did not.

Information on bicycle related injuries presenting to a trauma centre in Hong Kong was published by Yeung et al. (2009). Of the trauma patients presenting to an Emergency Department each year, 698 (3.0 %) were bicycle related injuries and of those, 473 patients had been cycling for exercise or recreation and 225 were cycling for transportation purposes. The cohort included 223 younger patients (≤ 15 years), 203 patients aged 16-25 years; 246 patients 26-64 years and only 26 patients aged 65 years or more.

- "617 (88.4%) of bicycle related injuries only involved one bicycle. 61 (8.7%) patients were injured after a collision with a bicycle. 20 (2.9%) patients were struck by motor vehicles on the road. Patients in the older group were 9.3 times (95% CI 1.23–69.5) more likely to be involved in a crash with a motor vehicle than the younger group."

- "Almost all patients with bicycle related injuries presented with external injuries including abrasions, contusions and lacerations. Other than external wounds, limb injuries were the most common, followed by head injury and facial injury. In this study, 67 (9.6%) victims had sustained a head injury and 11 of 67 (16.4%) head injuries were serious or critical. Head injuries were also the main cause of death after trauma."

Simulations were carried out by Bourdet et al. (2012) using Madymo software to evaluate the head impact area and velocity for single cyclist falls. Two situations of cycling fall were studied according to hypothetical configurations. One configuration consisted of a fall alone after skidding, and the second of a fall after hitting a curb.

The analysis of impact locations at head level showed that the impacts are very often close to the helmet rim line for both fall configurations. Also, for both fall configurations, the impact is predominantly in the fronto-parietal area. The results for head speed at the time just before impact showed that, for the normal components, the obtained values are approximately in the velocity range recommended by testing standards for the certification of helmets (5.42 m/s). Moreover, during head impact against the ground surface, a significant tangential component of the velocity is observed. Indeed, for a bicycle speed configuration of 5.5 m/s the head velocity presents a 35° incline versus the normal axis, whereas for a bicycle speed configuration of 11.1 m/s this angle is about 57°. This tangential component of the head velocity generates a rotational acceleration of the head and thus may increase the brain injury risk.

In a study by Brand et al. (2012), a technical and medical in-depth investigation of 289 bicycle-to-bicycle crashes including 578 victims with consequent injuries was performed. Most accidents occurred during the daytime under mostly dry road conditions. MAIS 1–2 injuries were sustained by 82.1 percent of all bicyclists and only 2.6 percent sustained severe injuries with MAIS 3+. The highest risk of injury was during front-to-front accidents. The head and extremities were at higher risk of injury compared with the thorax, abdomen, and pelvis. In the cohort of cases used by these authors, the average helmet use rate was described as being unsatisfactorily low.

Almost one third of the injured bicyclists sustained injuries to the head and extremities. The authors report that these body regions are more vulnerable for bicyclists than for occupants in motorised vehicles. They surmise, "bicyclists' heads and extremities are at high risk of injury." Bicycle–bicycle accidents showed less severe injury patterns compared with motorised road accidents.

McNally and Whitehead (2013) adopted an approach whereby they created individual computer simulation models of a bicycle, cyclist (with and without helmet) and vehicle. Four accident scenarios were modelled by these authors: Loss of control; where a wobble is simulated by a rotation applied to the handlebars. Curb impact; a form of loss of control where the cycle strikes a low curb at a glancing angle. Side impact by a vehicle; where the cycle is struck side-on by a car. Rear impact by a vehicle; where the cycle is struck rear-on by a car.

Helmets were found to be effective at reducing the predicted incidence and severity of head injuries over the full range of the simulations. Where a head impact occurred, the risk of AIS > 3 (e.g. a depressed skull fracture, prolonged unconsciousness, intracranial bleeding) was reduced by 40% (from 40% to 24%).

Cycle helmets are not going to protect in all situations and in their simulations McNally and Whitehead found that in 4 out of 21 (19%) of simulations with a head impact a helmet did not reduce the severity of injury. Each of these cases corresponded to a high energy impact with a vehicle that was fatal whether or not a helmet was worn. However the benefits of cycle helmets, even in accidents that would otherwise prove fatal, should not be underestimated. The McNally and Whitehead simulations suggested that a fatality could be prevented by helmet wearing in one third of cases.

The Madymo simulation work was continued by McNally and Rosenberg (2013). They chose to simulate a number of different scenarios that are representative of accidents that occur with child cyclists. The conditions modelled were a:

- Standard fall test – this test simulated a loss of control of the bicycle. A rotational velocity was applied to turn the front forks of the bicycle to reproduce a sharp turn or accidental swerve by the cyclist.
- Curb drop test – The curb drop test involved the bicycle moving off a curb edge of height 0.12 m.
- Wall impact test – The wall impact test involved a collision with a stationary vertical plane or "wall". This was 0.25 m in height which was a little over the mid-height of the bicycles wheels.
- Vehicle collision test – This test simulated a cyclist travelling in front of the car, perpendicular to its direction of travel. The cycle speed was kept constant at the mid-range speed of 4.5 m/s and the test was run at 3 different vehicle speeds; 8.9 m/s, 13.4 m/s and 17.9 m/s (20, 30 and 40 mph).

In almost every simulation, wearing a helmet reduced the probability of each AIS level of injury. The effectiveness of the helmet varied according to the scenario. It was most effective in the 'curb drop' simulation for all injury levels and in the standard fall and 8.9 m/s vehicle impact simulations for severe and fatal injuries. It was least effective in the 'wall impact' simulation where the probability of head injury was low even in the without-helmet case, and in the 17.9 m/s vehicle impact test, where the probability of head injury was high even when wearing a helmet. Helmet wearing appeared to have only a marginal effect on the potential for rotational injuries but was protective in terms of rotational acceleration in 3 out of 3 situations and rotational velocity in 2 out of 3 simulations.

In general the probability of neck injuries was low in non-vehicle collision simulations. Helmet wearing was found to be slightly protective. In the vehicle collisions the probabilities of neck injuries were in general smaller than the corresponding head injuries. Again helmet wearing was found to be slightly protective.

McNally and Rosenberg state that the results demonstrated that helmets are more effective for non-vehicle collision accidents such as falls. "For such accidents and for low speed vehicle collisions a helmet can almost eliminate the probability of a fatal head injury. These types of off-road accidents are the ones children are most commonly involved with and what helmets are really designed for."

In the Netherlands, 190 people die annually and more than 9,200 sustain serious injury in a bicycle crash (SWOV, 2012). A third of these seriously injured bicycle casualties are diagnosed with head or brain injuries (32%).

- "Of the cyclists with serious injury who are admitted to hospital following a crash with motorized traffic, almost half (47%) are diagnosed with head/brain injury. After crashes not involving motorized traffic this is the diagnosis for just under one third (29%) of the cyclists.
- Proportionally, head/brain injury occurs most frequently among children and youths. In crashes with motorized traffic more than 60% of the young seriously injured cyclists (0-17 years old) have sustained head/brain injury, compared with an average of 47%; in the case of crashes not involving motorized traffic, the percentages range from 33 to 56% for these age groups (compared with a 29% average).
- Approximately three-quarters of all head/brain injury sustained by cyclists are the consequence of crashes not involving motorised traffic (n=2,229). For young children (0-5 years old) as many as nine out of ten head/brain injuries are the consequence of bicycle crashes not involving motor vehicles. These are mostly cyclist-only crashes, i.e. crashes without another road user being involved, or crashes into an object.
- The risk (incidence rate per kilometre travelled) of head/brain injury in crashes not involving a motor vehicle is particularly high for children in the age groups 0-5 and 6-11 years old; for cyclists over 65 the risk increases rapidly as they get older."

Mehan et al. (2009) analysed retrospectively U.S. data from patients 18 years and younger who were seen in emergency departments (EDs) between 1990 and 2005, for injuries received while operating a bicycle. Children with head injuries were more than 3 (relative risk, 3.63) times as likely to require hospitalisation and were almost 6 (relative risk, 5.77) times more likely to have their injuries result in death.

Children between the ages of 5 and 14 years accounted for 78.6 % of the injuries. This age group also had the highest injury rates (7.54 injuries per 1000 children aged 5-9 years and 7.98 injuries per 1000 children aged 10-14 years). Contusions and abrasions were the most common injury diagnoses for children 9 years and older, while lacerations were the most common injury diagnosis for children younger than 9 years. The upper extremities (32.7 %) and lower extremities (24.1 %) were the most frequently injured body regions, followed closely by injuries to the face (21.4 %) and head (12.4 %). Lacerations (64.9 %) were the most common type of facial injury, while concussions, contusions, and internal organ injuries accounted for 68.4 % of injuries to the head. For children 8 years and younger, the face was the most frequently injured body part.

When location of injury was recorded (57.9 % of the cases), 47.5 % of the injuries occurred at home, 39.4 % took place on the street, and 7.2 % happened at a sports recreation facility. Compared with children who were injured in other locations, children whose injury occurred on the street were more than 2 (RR, 2.36; 95 % CI, 1.92-2.90) times as likely to require hospitalisation and were more than 11 (RR, 11.42; 95 % CI, 3.76-34.66) times as likely to sustain an injury that resulted in death.

Evaluating the head injury severity in cases of collisions with passenger cars in accordance with AIS (the Abbreviated Injury Scale), Otte and Haapser found that for traffic accidents with personal injury, and thus with injured bicyclists, 72.7% of the bicyclists with helmets remained unharmed in the head, compared with only 61.3% of those without helmet. Amongst the persons suffering from head injuries, soft tissue injuries occurred in 23.7% of the cases (without helmet 34.6%), face fractures in 2.7% (without helmet 2.9%), skull fractures in 0.6% (without helmet 1.1%), basal skull fractures in 0.3% (without helmet 0.6%), a concussion in 6.9% (without helmet 7.1%), brain injuries in 0.8% (without helmet 1.9%) and cerebral haemorrhage in 0.3% (without helmet 0.8%).

The use of a bicycle helmet resulted less frequently in injuries of the cranio-cerebral area. Both with and without helmet various injuries in the mid-face and lower jaw areas were still found. These are parts of the head that are not covered by the protective areas of typical bicycle helmets. In particular bicyclists without helmets showed a high incidence of injuries in the area of the upper half of the head; the left and right areas of the forehead were hit in almost equal measure (left: 142 soft tissue/2 fractures; right: 123 soft tissue/3 fractures). In 16.7% (379 of 2,275) cases the injuries were located inside the skull (if commotion, contusion, compression and cerebral haematoma as well as ventricle haemorrhaging are grouped together).

Otte and Haasper draw attention to the finding that, “If one compares the helmet and non-helmet situations exclusively for persons within a comparable accident severity range, e.g. in the case of an impact speed of 30–50 km/h of the passenger car, this again confirms the fact that fractures and severe internal brain injuries do not usually arise if a helmet is worn.”

Police reported cycling-related crashes were obtained by Boufous et al. (2012) from VicRoads (Road Authority of Victoria) for a five-year period. There were 6,432 cyclist crashes reported to the police in Victoria between 2004 and 2008 with 2,181 (33.9 %) resulting in severe injury of the cyclist. As in their 2011 study, the authors note that crashes reportable to police are those that occurred on public roads where at least one person was killed or injured and the crash was attributable to vehicle movement.

Multivariate analysis showed that a number of cyclist characteristics (age, helmet use) as well as crash and road characteristics (crash type, light condition, location of the crash, road speed limits and road curvature) were independently and significantly associated with the severity of injury in cyclists involved in traffic crashes. Not wearing a helmet increased the risk of severe injury in cyclists involved in police-recorded traffic crashes by 56 %.

Considering trauma registry data in New South Wales, Dinh et al. (2013) showed that helmeted bicyclists had fewer head injuries, severe head injuries and requirements for rehabilitation than non-helmet wearing cyclists. Also for the 50 patients with severe head injury, hospital costs were around three times higher in non-helmeted patients compared with helmeted patients (including bicycle and motorcycle cases in this instance).

In France, the Rhône county (1.6 million inhabitants) is covered by a road trauma registry that includes emergency department visits, hospital admissions, and fatalities. Over the 1998–2008 period, 13,797 cyclist casualties were identified. The injuries sustained were coded using the Abbreviated Injury Scale (AIS) for injuries to the head (AIS1+ and AIS3+), face (AIS1+), or neck (AIS1+). The study by Amoros et al. (2012) used a case–control design where the control group included cyclists injured below the neck. They adjusted for age, gender, and type of crash, as in a previously published Cochrane review. Then also adjusted for injury severity based on non-head, face, or neck injury, and when relevant, for crash location: type of road, urban/rural area.

Of the 8,373 injured cyclists with known helmet status, 1,720 (26%) were wearing a helmet at the time of the crash and 6,653 were not. Helmeted and non-helmeted injured cyclists differed. This study indicates that the helmet is associated with a decreased risk of head injury (whatever the severity), and the decrease seems greater for the risk of serious head injuries. For serious head injuries, the decrease in risk is of the same order of magnitude as that estimated by the Cochrane review (Thompson et al., 2000): the 'Cochrane-like' analysis leads to an OR of 0.30 for head AIS3+ injuries, and the Cochrane review finds an OR of 0.31 (0.23 to 0.42) for brain injuries (which are roughly equivalent).

Cyclists injured in towns were generally less severely injured than those injured outside towns for both bicycle-only crashes and collisions with a motor vehicle (Amoros et al., 2011). Amoros et al. (2012) also identified an interaction between helmet wearing (yes/no) and crash setting (urban/rural) for the risk of serious head injuries, with the protective effect being much greater (by a factor of five) for bicycle crashes in rural areas. This could be partly due to insufficient adjustment for crash severity (cyclists crashing in rural areas were more seriously injured than those crashing in urban areas, probably because of higher speeds). Another possible explanation lies in the fact that crashes in rural areas were much more likely to involve sports cyclists than commuting cyclists, and it may be that sports cyclists wear better helmets and/or know how to adjust them better.

Consistent with the results of the Cochrane review, the Amoros et al. study indicated that helmet wearing lowers the risk of facial injuries. However, it was not conclusive about the risk for neck injuries. Age (in this case, being adult) was associated with an increased risk of neck injury and a higher rate of helmet wearing among injured cyclists (which was probably explained by more helmet wearing among sports cyclists). The lower adjusted OR of 1.18 was not significant but the statistical power was low; if there was an increase of risk, it would be small.

A case–control study of 6,745 cyclist casualties resulting from collisions with motor vehicles in New South Wales, Australia during 2001-2009 was reported by Bambach et al., (2013). The findings indicated that helmet use was significantly associated with reduced risk of head injury by up to 74%. This included reductions in risk of up to 78% for skull fracture, 72% for intracranial injury, 74% for concussive injury and 80% for open head wounds.

This is one of the first case–control studies examining cyclists, helmet use and head injury severity that have used linked police reported crash data, hospital admission and mortality data. This study found that the odds of sustaining a head injury increased 1.98–3.89 times for cyclists that were not wearing a helmet, depending on the severity of injury considered. Similar odds were determined for the particular injuries of skull fracture 2.29–4.61), intracranial injury (1.60–3.52) and open wounds (5.00).

Non-helmeted cyclists were more likely to be cycling on the footpath (34.4% compared with 12.9%) and in speed zones of 50 km/h or less (56.9% compared with 50.0%), and less likely to be cycling on highways or freeways (8.3% compared with 12.6%). Overall, non-helmeted cyclists were more likely to be seriously injured in body regions other than the head (9.5% compared with 7.3%; Bambach et al., 2013).

There are limitations to the Bambach et al. study noted by the authors. In particular they comment that, "This study identified cyclist and motor vehicle crashes using police-reported data; however, not all crashes are reported to police. Therefore, police-reported data are a sample of all crashes and could suffer from selection bias."

McIntosh et al. (2013) considered a sample of a total of 220 motorcycle riders, six motorcycle pillion passengers and 137 pedal cyclists. Data for pedal- and motor- cyclist injuries were extracted from the trauma registry of St. George Public Hospital (SGH) in Sydney, a level one trauma centre. Approximately eighty percent of patients wore a helmet at the time of the crash: 195 motorcyclists riders and passengers (88.6%) and 87 pedal cyclists (63.5%). Binary logistic regression for discrete head and brain injuries identified that there was a significantly lower likelihood of a pedal cyclist experiencing a head injury (Exp(B) = 0.21), concussion (Exp(B) = 0.46), or intracranial injury (including concussion) (Exp(B) = 0.33) associated with wearing a helmet.

The most frequent main body region of injury for all pedal cyclists was the head (37.2 %). The most frequent main body region of injury for unhelmeted pedal cyclists was the head (60.0 %) and for helmeted pedal cyclists the upper limb (33.3 %).

3.3 Features expected to affect helmet effectiveness

The Canadian Cycling Association's CAN-BIKE programme to promote cycling safety has been taught in Canada since 1985, and local educational programmes, media campaigns, and subsidised or free helmet distribution programmes are also known to have occurred in Canada around the time legislation was implemented. Similarly, changes to cycling infrastructure over the study period (for example, traffic calming, and designated bicycle lanes and routes) could have confounded associations with helmet legislation. In provinces and territories without legislation, several municipalities implemented helmet legislation between 1994 and 2003. Notably, seven municipalities in Newfoundland and Labrador, including St John's, the province's largest municipality, implemented bylaws that may have contributed to the steep decrease in cycling rated head injury rates observed in this province (Dennis et al., 2013).

It is possible that the effectiveness of helmets is greater for mild and moderate head injuries than for the severe head injuries captured by hospital admission data (Dennis et al., 2013). Diagnostic and prognostic improvements over time that allowed for the treatment of patients with mild and moderate head injuries in emergency rooms, as opposed to in inpatient hospital wards, could have further impeded the ability to detect an effect of helmet legislation, if one exists.

As mentioned in Section 3.1.1, good helmet fit and retention are likely to be key requirements for helmets to function as intended. The mere use of a helmet is not enough to provide full protection to cyclists during a crash. Bicycle helmets need to be worn correctly to help prevent head and brain injuries from bicycle collisions, and to help reduce morbidity and mortality.

A correctly worn helmet is considered to sit straight and horizontal on the head, and not too far forward to cover the eyebrow or too far back on the head so that the forehead is exposed. The helmet should not be too loose and the wearer should have the buckle or helmet straps fastened. The helmet straps must be fastened with approximately one finger width space between the chin and the straps. Furthermore, the helmet should be stationary when movement is attempted. A helmet is considered to be in an incorrect wearing position when it is tilted either forward or backward, not securely strapped under the chin, has more than two finger breadths space between the head and the helmet, and moves either front-to front, side-to-side, or rotationally.

The purpose of the study by Hagel et al*.* (2010) was to examine patterns of incorrect bicycle helmet use based on field observations. Observational surveys were conducted from June to September 2000 and from June to October 2006. Data were collected from 480 sites in Edmonton, Calgary and surrounding areas. Observations were made on 9,734 cyclists; of these, 5,842 (60%) were wearing a bicycle helmet, 20 (0.2%) were wearing another type of helmet and 3,872 (40%) were not wearing a helmet (helmet use was not recorded for two observed cyclists). Of the 5,862 cyclists wearing a helmet, 876 were using it incorrectly.

This follows the systematic review of Lee et al*.* (2009) which considered 11 studies describing the prevalence of proper or improper helmet use among cyclists. This had shown that correct helmet use varied from 46 % to 100 % but depended on the definition of correct use, whether the use was self-reported or observed and the availability of educational programmes.

Observers coded incorrect use into categories of 'not a bicycle helmet', 'straps not properly fastened', 'too far forward' or 'too far back'. More than half the incorrect use in children (53%) and adults (51%) was the result of wearing the helmet too far back on the head. For adolescents, the most frequent type of incorrect use was not having the chin strap correctly fastened (48%), followed by wearing the helmet too far back (38%). Among children under the age of 13, 21% (95% CI 18.6 to 24.1) were using the helmet incorrectly.

An important finding could be highlighted based on this study, that children were more likely to wear their bicycle helmet incorrectly than adults, though there seems to be some difference between those < 13 and ≥ 13 years old.

Romanow et al*.* (2014) calculated crude odds ratios (ORs, with 95% CIs) for the association between helmet fit and head or facial injury. They also examined the relationship between helmet position during the crash and head or facial injury.

Injured cyclists were recruited from Emergency Departments in Canada. In total, 4,960 injured cyclists were screened for eligibility and 3,111 (63%) agreed to participate and were enrolled into the study. Of these, 2,336 (75%) were wearing a helmet at the time of the crash. There were 297 cyclists with a head injury, 289 facial injury cases and 1,694 controls. There were 64 participants who had both head and facial injuries.

Based on the crude estimates, poor helmet fit significantly increased the odds of head injury relative to the excellent fit category (OR = 3.26, 95% CI: 1.08–9.83). If the helmet tilted back (OR = 2.76, 95% CI: 1.47–5.18), shifted to the side (OR = 1.87, 95% CI: 1.03–3.42), or came off (OR = 6.77, 95% CI: 3.08–14.86), the odds of head injury increased significantly relative to the ''stayed centred'' group. When adjusted for BMI, cycling frequency and cycling speed, only those helmets that tilted back were associated with an increase in the odds of facial injury (OR = 4.49, 95% CI: 2.30–8.77).

These findings on the importance of helmet fit provide a better understanding of the potential protective effect of bicycle helmets. Previous studies that documented that helmet use (vs. non-use) reduces the risk of a head or brain injury may in fact underestimate the protective effect of helmets given that it is likely that a number of the participants in these studies were wearing a poorly fitting helmet or using the helmet incorrectly (e.g. strap not fastened). If so, this may have implications for the promotion of helmet use, which should include a focus on how to wear helmets correctly in order to achieve the maximum protective benefit.

More fundamentally, helmets need to be worn to be of any benefit in their intended use. The Health Behaviour in School-aged Children (HBSC) study is a cross-national survey in Canada. Of 26,078 students surveyed within the HBSC study (mostly aged 11-15; from 436 schools in 8 provinces and the 3 territories), 74 % of them reported riding a bike in the last 12 months. Among these 19,410 students who reported that they rode bicycles, 43 % of riders reported never wearing a helmet, 32 % inconsistently wore a helmet and only 26 % reported always wearing a helmet (Davison et al., 2013).

It is also worth noting that helmets for use during bicycling should only be worn for that purpose. Incidence of injuries related to inappropriate helmet use have been noted, for instance; death due to asphyxiation (Byard et al., 2011).

3.4 Summary of helmet effectiveness

Within their performance limits, cycle helmets are designed to:

- Reduce head acceleration, which is correlated with a reduction in some types of traumatic brain injury;
- Reduce head impact forces and distribute those forces over a larger area of the cranium, which is correlated with a reduction of the risk of cranium fracture, and therefore also the risk of secondary brain injuries due to displaced fragments of the fractured cranium;
- The reduction of head acceleration will also reduce the risk of diffuse brain injuries due to rotation of the head, although it should be noted that additional reduction of the risk of diffuse brain injuries could accrue if a suitable test to reduce rotation was introduced into helmet standards;

Nevertheless, the energy absorbing capacity of a cycle helmet is finite and they cannot be expected to mitigate head injury in every collision.

Cycle helmets dramatically reduce head injury metrics in tests with dummy headforms

- Bicycle helmets changed the probability of severe brain injury from extremely likely (99.9% risk at both 1.5 and 2 m drops) to unlikely (9% and 31% risk respectively) (Cripton et al., 2014)
- Bicycle helmets reduced all injury metrics, including rotational acceleration, at different drop heights with and without a lateral velocity component (McIntosh et al., 2013)

Cycle helmets dramatically reduced head acceleration and markedly increased the crush strength in tests with paediatric skulls (Mattei et al., 2012)

Cyclists are injured:

- More often than recorded by the police (e.g. Airaksinen et al., 2010)
- At home (47.5% of the injuries), on the street (39.4%), and at a sports recreation facility (7.2%; Mehan et al., 2009) for children aged 18 and younger.
- And will require radiography (70.4 %), a CT scan (3.1 %), hospital admission (25.1 %) for 2.4 days on average (for younger patients; Yeung et al., 2009)

More cyclist injuries are attributable to single-cycle accidents than to collisions with other vehicles, e.g.

- 88.4 % in collisions with no other vehicle (Yeung et al., 2009)
- 65.4 % of cases for child cyclists (Klin et al., 2009)
- 73.7 % of cases for UAE nationals under 15 years old (Hefny et al., 2012)

There is a higher risk of a serious cyclist head injury in collisions with a motor vehicle than in other collision types (including single-cycle accidents) (SWOV, 2012; Klin et al., 2009)

Nevertheless, the majority of cyclist collisions resulting in head injury involve no other vehicle (e.g. SWOV, 2012)

- Approximately three-quarters of all head/brain injury sustained by cyclists are the consequence of crashes not involving motorized motorised traffic
- For young children (0-5 years old) as many as nine out of ten head/brain injuries are the consequence of bicycle crashes not involving motor vehicles
- Are a particularly high risk from crashes not involving a motor vehicle for children in the age groups 0-5 and 6-11 years old (SWOV, 2012)

Cyclist head injuries:

- Are more likely to require hospitalisation when sustained by children compared with other injuries (Mehan et al., 2009)
- When sustained by children, are more likely to result in death compared with other injuries (Mehan et al., 2009; Airaksinen et al., 2010)
- Are more common for children and youths (SWOV, 2012)

Helmet wearers

- Sustain fewer head injuries than unhelmeted cyclists (McIntosh et al., 2013; Otte and Haasper, 2010; Dinh et al., 2013 Bambach et al., 2013)
    - Particularly to the cranio-cerebral area of the head (Otte and Haasper, 2010)
    - Have a lower likelihood of experiencing a concussion or intracranial injury than unhelmeted cyclists (McIntosh et al., 2013; Otte and Haasper, 2010)
    - Have a lower risk of AIS3+ head injuries compared with non-helmeted cyclists (OR 0.3; Amoros et al., 2012)
    - Have a lower likelihood of experiencing a soft tissue injury or skull fracture than cyclists involved in a passenger car collision not wearing a helmet (Otte and Haasper, 2010)
    - Have a lower risk of facial injuries (Amoros et al., 2012)

  - Have a marginally lower risk of neck injuries (McNally and Rosenberg, 2013)
- Have fewer requirements for rehabilitation (for cyclists of all ages) than non-helmet wearers (Dinh et al., 2013)
- Will see more effect from their helmets in non-vehicle collisions such as falls than in collisions with another vehicle (McNally and Rosenberg, 2013)

4 The impact of cycle helmet legislation on injury outcomes

The amount and quality of evidence gathered for the different outcomes (the effects of helmet legislation on wearing rates and on injuries) varied, and as such the specificity with which we can state conclusions also varies for each outcome. This section considers helmet wearing rates and the potential injury reduction associated with mandatory cycle helmet legislation.

4.1 Helmet wearing rates

This section considers whether mandatory cycle helmet legislation impacts on wearing rates. Studies measuring cycle helmet wearing rates usually rely on observational data from selected sites at selected time periods or from self-report data. Neither of these methods is perfect for reflecting actual wearing rates therefore this section has again sought to determine how the weight of evidence from published studies meeting the quality criteria can inform the conclusions, without necessarily discussing specific methodologies in detail.

Of the five studies reported in Macpherson and Spinks' (2008) systematic review, two assessed the impact of mandatory bicycle helmet legislation for children on helmet wearing rates, while one assessed the impact of an enforcement programme of existing legislation on wearing rates. The two studies following the introduction of legislation reported increases in wearing rates for children (i.e. those affected) but not for adults (who were not covered by the legislation) (Hagel et al., 2006; Ji et al., 2006). The impact of enforcement found lasting effects (up to two years follow-up) for children, although it should be noted that in the pre-enforcement observations no cyclist wore a helmet. At two years, 54% of children observed wore a helmet but no adults observed wore a helmet. Overall the results of Macpherson and Spinks' (2008) review support those of an earlier systematic review on the effect of legislation on wearing rates, that suggested the increase in helmet use ranged from 5% to 54% (Karkhaneh, 2006).

Research from the Australian states of Victoria and Queensland, summarised by Haworth et al. (2010), all appear to demonstrate effects of legislation on helmet wearing rates, and with a similar pattern. In Victoria wearing rates were increasing prior to legislation (from around 5% in 1982/83 to 31% in 1989/90) but spiked following implementation of legislation to 75% in March 1991 (Cameron et al., 1992). In Queensland, the introduction of legislation also saw rates jump (from around 11-16% pre-legislation to 52%). The wearing rate has subsequently risen to 71% in 1997 and 77% in 2001 (Haworth et al., 2010). The impact of enforcement is also noted from Queensland's experience with rates increasing when a penalty and enforcement system was introduced 18 months after the legislation was implemented. A waiver system accompanied the enforcement for the first six months whereby the fine was waived if the offender showed evidence of having purchased a helmet with 14 days. The penalty for not wearing a helmet (as reported in 2010) is AUS$100, equivalent to a driver failing to stop at a school crossing (Haworth et al., 2010).

In Alberta, Canada helmet use for all bicyclists less than 18 years of age was mandated from 1st May 2002. The penalty for not wearing an approved helmet is reportedly CAN$69. Evaluation has shown an increase in helmet use after legislation among children under 13 (75–92%) and adolescents 13–17 years (30–63%) with a less notable increase for adults (52–55%) not affected by legislation (Karkhaneh et al., 2011a,b). It is reported that these increases in wearing rates were largely a result of the legislation alone, in the absence of any associated enforcement initiative (Karkhaneh et al., 2011a).

Denis, Potter, Ramsay and Zarychanski (2010) compared the impact of bicycle helmet legislation across the Canadian provinces. In Canada, four of ten provinces mandate helmet use for all ages of cyclist, two mandate helmet use for cyclists under 18 years old, three have no legislation and one area has a singular territory within the province with legislation. A comparison of self-reported wearing rates suggests that states with all-ages legislation had significantly higher wearing rates for adults and youths (those under 18 years old) than provinces with partial or no legislation. Wearing rates for provinces with partial legislation similarly had higher adult and youth wearing rates than provinces with no legislation. For example, Novia Scotia with all-ages legislation has a higher bicycle helmet wearing rate (Youths: 77.5%; Adults: 71.4%) than Ontario with <18 legislation (Youths: 46.7%; Adults: 38.9%), who in turn have a greater wearing rate than Saskatchewan with no legislation (Youths: 32.9%; Adults 25.1%) (Denis et al., 2010). The authors conclude that these differences should be considered when legislation is developed.

In summary, the effect of mandatory bicycle helmet legislation on wearing rates has been measured by observation, self-report and occasionally hospital admission data. While none of these methods are perfect, the pattern of results, and therefore the weight of evidence can allow the following conclusions:

- Mandatory cycle helmet legislation increases helmet wearing rates for the population affected.
- Mandatory cycle helmet legislation may increase helmet wearing rates for the population affected even in the absence of enforcement, although wearing rates are likely to improve with associated enforcement activities.
- Mandatory cycle helmet legislation for all ages may result in greater helmet wearing rates for both young people and adults when compared with partial legislation.

While the majority of cyclists involved in the police-reported crashes analysed by Boufous et al. (2012) had been wearing a helmet (74.1%), this proportion was only 57.1% in children aged under 10 years and 60.2% among adolescents aged 10 to 19 years (results not shown) despite the existence of compulsory helmet wearing laws in Victoria, Australia.

Walter et al. (2011) reported that helmet wearing among those involved in traffic accidents increased from approximately 20% to more than 60% among children and over 70% for adults within two months of the legislation coming into effect. A small additional increase may also have occurred subsequent to the initial rapid change. The actual rates of helmet wearing may have been higher than those shown since around 20% of TADS records each year were missing this information. The post-law rates of helmet wearing approximately concur with the RTA surveys, in which helmet wearing rates over 70% among children and more than 80% for adults were observed in the first survey following legislation and remained close to this level in subsequent surveys.

4.2 Compulsory helmet wearing legislation and injury

Compulsory helmet-wearing legislation has been introduced in a number of countries (not necessarily nation-wide) including Australia, New Zealand, Canada, Finland, Iceland, Israel, Sweden, USA, and Spain. Some laws require only children to wear a helmet (e.g. under 15 years old in Iceland and Sweden); others require adults to do so as well (e.g. Australia and New Zealand). In Spain all riders must wear a helmet but with specific exceptions (urban areas, hot weather, and uphill).

Studying the impact of such legislation is often confounded by factors out with the control of researchers, such as any concurrent change in cycling rates (related or unrelated to the legislation), unreported collisions and other changes implemented during the time of study (e.g. changes in infrastructure or speed limits for motor vehicles, or in other safety-related legislation such as drink-driving laws). Another cited issue is the potential for ‘risk compensation’ to occur. This is where either cyclists or motorists change their behaviour as a result of the cyclist wearing a helmet such that any benefit accrued from wearing the helmet is offset by an increase in risk in other areas (for example, the cyclist riding faster or motorists passing closer to the cyclist). While some Norwegian (Phillips, Fyhri & Sagberg, 2011) and British (Walker, 2007) research has been cited as being suggestive of this phenomenon, reanalysis and re-interpretation appears to negate any support for this notion (e.g. Olivier & Walter, 2013; Olivier et al., 2013c).

An ideal assessment of the impact of helmet legislation on head injuries among cyclists would require individual level population wide data on cycling exposure and helmet wearing. The lack of such data is a fundamental obstacle to generating accurate population level rates of cyclist head injuries and examining their trends in light of compulsory helmet legislation (Walter et al., 2011).

The ‘gold standard’ evaluation methodology – a randomised control trial – would require assigning a very large number of non-helmet wearing cyclists at random to control (no helmet wearing) and treatment (helmet wearing) groups and then measuring their exposure, incidents and injuries over a long timeframe. Such a study would require significant resources and is likely to be considered unethical given the evidence discussed in Section 3 that helmets are effective in the event of a collision. For this reason, case-control studies – where before and after legislation effects on cyclists are compared with an existing comparison (control) group – have been used to try and identify differences between groups of cyclists wearing a helmet and those not wearing a helmet. Studies of this type are imperfect and can be open to interpretation depending on the preferred method of analysis utilised by the researchers. The design and interpretation of such studies and analyses have led to much of the debate within the scientific and non-scientific literature on whether legislation for compulsory cycle helmet wearing is appropriate. It is beyond the scope of this review to consider all of the methodological benefits and weaknesses employed in all published studies; it is suggested that interested readers follow up the references cited for additional detail and discussion.

In order to reach conclusions regarding the evidence in such circumstances the most appropriate approach is to consider both the quality and the weight of the evidence; that is, what is the most common finding when only the best available evidence is considered?[1] The best available evidence here is defined by the criteria outlined in Section 2.3.

A systematic review taking this approach evaluated published research evidence of the effect of bicycle helmet legislation up to January 2007 (Macpherson & Spinks, 2008). No randomised controlled trials were found but five published case control studies from North America met the selection criteria. All studies evaluated the effect of mandatory bicycle helmet legislation applied to children across four jurisdictions. Two of the studies assessed the impact of bicycle helmet legislation on head injuries (Lee et al., 2005; Macpherson et al., 2002), two assessed the impact on helmet wearing rates (Gilchrist et al., 2000; Hagel et al., 2006) and one studied both (Ji et al., 2006). Of the three studies using head injuries as an outcome measure, two found significant reductions and one found a non-significant reduction. The authors concluded that bicycle helmet legislation appears to be effective for reducing head injuries, but that the evidence base is clearly limited. While the limitations of the studies included in the review are not insignificant, they remain those considered to be examples of the best available evidence. When their results are collated they suggest a reduction in head injuries resulting from the implementation of mandatory cycle helmet legislation for children. While the extent of any reduction may be debated, there is crucially no suggestion of any potential increase in head injuries; that is, there was no evidence to suggest that mandatory cycle helmet legislation was harmful in terms of its effect on injury outcomes.

Further evaluation of North American mandatory bicycle helmet legislation has been published since Macpherson and Spinks (2008). For example, Meehan III et al. (2013) compared fatality rates of children aged under 16 years involved in collisions involving a motor vehicle between states with and without mandatory bicycle helmet legislation. The authors attempted to control for other motor vehicle legislation and state-specific economic factors and concluded that fatality rates for child cyclists when involved in a collision with a motor vehicle were lower in the 16 states with bicycle helmet laws. While there may be alternative explanations for the differences between states' child cyclist fatality rates, Carpenter and Stehr (2011) also conclude that for the 1990s state bicycle helmet laws were associated with statistically significant reductions in bicycle fatalities among youths aged 0-15 but were not associated with statistically significant changes in bicycle fatalities among 16-30 year-olds. Mandatory bicycle helmet legislation across the USA is predominantly targeted at children.

In addition to North American literature, a subsequent Australian review of relevant research is provided by Haworth, Schramm, King and Steinhardt (2010). Of the research reviewed is an evaluation of bicycle helmet legislation (for all ages) in Queensland, Australia which was found to be associated with a reduction in the number of cyclist crashes resulting in fatality or hospital treatment (King & Fraine, 1994). King & Fraine (1994) attempted to control for any changes in cycling rates by comparing changes in head injuries with other body injuries over the timeframe of the study. It is reported that head injuries reduced more than other injuries. This reduction apparently occurred in the absence of any enforcement of the legislation and it is reported that there was a further (larger) reduction in head injuries (when compared with other body injuries) when

[1] Due to the numerous methodological approaches and analysis techniques employed across the published literature, the authors have deliberately refrained from noting the extent of any reported impact on injuries or injury rates resulting from the implementation of mandatory bicycle helmet legislation. Instead the direction of any impact is reported only; that is, whether injury rates have reduced, increased or stayed the same.

enforcement of the legislation was introduced. A reduction in injury rates in Brisbane, Queensland specifically is similarly reported by Thomas et al. (1994).

A series of reviews of bicycle helmet legislation (for all ages) in Victoria, Australia also appear to suggest a pattern of injury reduction following implementation (see Haworth et al., 2010). In New South Wales, Australia an analysis of head injuries versus other body injuries suggested that injury rates potentially attributable to cycle helmet legislation reduced to a greater degree over the time period studied (Walter et al., 2011). Subsequent critique cast some doubt on the original analysis (Rissel, 2012) although re-analyses of the same data appears to support a benefit of cycle helmet legislation and a reduction in head related injuries (Olivier, 2013a,b)

In Canada, an evaluation of bicycle helmet legislation for children aged 16 years and under found a reduction in mortality rate for cyclists in this age group when compared with adults over the same timeframe (Wesson et al., 2008). Karkhaneh et al. (2013) also report a reduction in child head injuries in Alberta, Canada following the implementation of mandatory bicycle helmet legislation for those under 18 years old. The study compared child cyclist emergency department and hospitalisation rates with adults and pedestrian injury rates and concluded that the reduction for children was consistent with a bicycle helmet legislation effect. Dennis, Ramsay, Turgeon & Zarychanski (2013) report that across Canada, rates of admissions to hospital for cycling related head injuries reduced more in provinces with helmet legislation than in those provinces without helmet legislation. However, a time series analysis up to one year after legislation suggests that rates were already decreasing before the implementation of legislation, and the rate of decline was not appreciably altered on introduction of legislation. They suggest that while helmets reduce the risk of head injuries, in the Canadian context of existing safety campaigns, improvements to the cycling infrastructure, and the passive uptake of helmets, the incremental contribution of provincial helmet legislation to reduce hospital admissions for head injuries seems to have been minimal.

These studies from Canada highlight the difficulty of determining the real impact of mandatory bicycle helmet legislation on injury outcomes. As noted earlier in this section, the literature is broad, with varied methods and analyses undertaken, that can support most perspectives. There is, for example, a report of increased cycling injury risk following the mandating of bicycle helmets in New Zealand (Clarke, 2012), although a fairly robust rebuttal of this analysis suggests that the original paper is selective in the data used for analysis and alternatively demonstrates a reduction in serious head injuries (see Olivier et al., 2013c).

In summary, it is beyond the scope of this review to critically evaluate all of the analyses and methods reported within the literature to determine the impact of mandatory cycle helmet legislation on injury outcomes. In order to summarise the evidence the weight of evidence from studies of sufficient quality has been considered. When this is done the following can be reasonably concluded (when considering injury outcomes only):

- Mandatory cycle helmet legislation does not appear to cause harm in terms of its impact on injuries; that is, there is no evidence of an increase in injuries following the implementation of legislation.
- Mandatory cycle helmet legislation is likely to result in a reduction of reported head related trauma, particularly for children.

5 The impact of cycle helmet legislation on cycling activity

This section summarises the evidence relating to any effects of mandatory cycle helmet legislation on levels of cycling activity. Understanding the effect on cycling activity is important as cycling is known to be a healthy activity (Andersen et al., 2000) with additional environmental benefits (when it replaces a journey made by a conventional motor vehicle). If mandatory cycle helmet legislation acts as a barrier to cycling then these associated benefits may be lost and outweigh any safety benefit that might have accrued.

An argument that has been advanced by some researchers is that mandatory helmet legislation could discourage cycling if helmets are considered to be excessively costly, uncomfortable or unfashionable, or if someone without out one simply does not want to break the law. It is also possible to argue that mandating helmets could be perceived by the public as an act by authorities to improve cycling safety in general, thus overcoming what is known to be a major barrier towards cycling.

Evidence is more important than intuitive-sounding counter-arguments, whichever way they are aligned with regard to the debate. The most commonly cited effects on actual cycling participation are from evaluations of cycling rates in the early 1990's following the implementation of mandatory helmet wearing for all ages in various states in Australia. For example, in Melbourne, compulsory helmet legislation was introduced on 1st July 1990. Estimated bicycle use across the city was evaluated based on observational data pre- and post-legislation. Between December 1987 and May 1992 the amount of cycling by adults was reported as having doubled; however, cycling by children (5-11 years) was reported to have decreased by 10% in 1992 following legislation (compared with 1990 levels) and by 46% (compared with 1990 levels) for those aged 12-17 years (Finch, Heiman & Neiger, 1993). These results suggest that the amount of time spent cycling had reduced, but not necessarily the number of cyclists. Finch et al. (1993) also reported that while there was a reduction in cyclists observed in the first year following legislation, there was an increase in the number of cyclists between 1991 and 1992, although the number of cyclists aged 12-17 years remained lower than pre-legislation levels.

Data from Victoria and New South Wales, Australia has also been cited as showing that cycling participation was lower than would have been expected were mandatory helmet laws not introduced (Robinson 1996; 2006). However, this work has been criticised and re-analysis of excluded data suggest that there is no evidence that adult cycling counts reduced as a result of helmet legislation (Olivier et al., 2013c). While child cycling counts reduced after legislation, they were reducing prior to implementation and further reductions cannot necessarily be associated with the legislation. Olivier et al. (2013) nevertheless propose that caution must be heeded when interpreting the results of either analysis using this data as it was collected to measure wearing rates rather than exposure.

In 1995 legislation was introduced in Ontario, Canada, requiring those aged less than 18 years to wear helmets when cycling. Before and after observational counts of the number of child cyclists (aged 5-14 years) per hour were performed in 1993-1997 and again in 1999. The data demonstrated significant variability from year to year such that no effect could be attributed to the introduction of legislation (average cycling levels were in fact higher in the year following legislation). Further analysis of Canadian provinces compared all-age legislation (introduced in 2003 in Prince Edward Island) with partial legislation (<18 years, introduced in 2003 in Alberta) and no legislation in other provinces (Dennis et al., 2010). Using Canadian Community Health Survey data rather than observed data, they conclude that there is no evidence that either partial or full legislation has discouraged cycling among adults or youths.

The results of the early Australian studies (or at least in Melbourne) are such that one questions why similar effects are not reported in Dennis et al. (2010). There are no clear explanations reported, or supported, in the literature and it may simply be due to differences in the study methodologies (e.g. observed versus survey data). It may also be due to differences between Australia and Canada given that no discernable change in cycling rates was detected in Ontario resulting from the introduction of legislation in 1995. It may also be hypothesised that the development of cycling and cycling equipment, particularly helmet design, changed dramatically from the early 1990's when legislation was introduced in Australian states to the mid-1990's and early 2000's when legislation was introduced in Canada. Helmet design improved, costs reduced and the prominence of helmets improved (as evidenced by their introduction to professional cycling from 2003). Voluntary helmet use in Australia was increasing prior to legislation (Haworth et al., 2010) and it could be argued would have continued to increase without legislation (albeit not reaching the level achieved by legislation for some years). Had legislation been introduced in Australia at the same time as in Canada, the impact on youth cycling activity may not have been as dramatic as that reported in the early 1990's – although this is of course speculative.

Analysis of states with and without helmet legislation in the USA may provide some support for this hypothesis. State helmet legislation in the USA tends to target children only (e.g. <16 years) and has been enacted through the 1990's into the 2000's (Carpenter & Stehr, 2011). Carpenter and Stehr report that while legislation resulted in an increase in youth helmet wearing rates, there was a modest but statistically significant 4-5% reduction in youth cycling participation. The reduction in youth cycling activity reported is not as dramatic as that of Finch et al. (1993), which, speculatively, may be associated with an increased acceptance of cycle helmets through the 1990's and 2000's alluded to above. Nevertheless, any reduction in cycling activity, particularly by young people, could result in a net health disbenefit to society. Carpenter and Stehr (2011), however, report that the reduction in youth cycling was not associated with a reduction in general physical activity, and suggest that cycling-discouraged-youths may have turned to unregulated activities such as skateboarding or using in-line skates instead. It is further concluded that helmet legislation has increased wearing rates and reduced fatalities, such that it is likely that the safety benefits outweigh the reduction in cycling, although addition research is recommended (Carpenter & Stehr, 2011).

5.1 Health costs and benefits

Weighing up the costs and benefits of cycling on health is complex and estimates can vary wildly depending on the figures used within any given model. The premise is that an individual who cycles benefits from the increased physical activity, in the short and longer term. Where their journey replaces a journey that would otherwise be made by car, the health benefits may be offset somewhat by inhaling air-pollution in dense traffic areas and increased accident risk (de Hartog et al., 2010, although see Andersen et al., 2000). At the same time, however, the replaced car journey has an additional benefit to society of reduced emissions. The health benefits are often argued to vastly outweigh the potential risks and disbenefits. For example, deHartog et al. (2010) suggest that for people who shift from car to bicycle the effect of increased physical activity results in larger health gains than the losses from air pollution and accident risk. To complicate the matter further, an increase in cycling may not actually result in an overall increase in a person's physical activity, as it may be associated with reduced activity in another domain (Forsyth et al., 2008). The converse of this is true as well of course; should a person stop cycling, that exercise may be offset by participation in alternative physical activity domains, resulting in no net health disbenefit (although again the findings from Andersen et al., 2000 are relevant here, in that cycling was found to have a protective effect on mortality even after other exercise was taken into account).

de Jong (2012) has attempted to devise a model with which costs and benefits can be compared to determine a cost-benefit ratio. While this approach has merit, some of the assumptions necessary are critical to the output and have been criticised (Olivier et al., 2013c). As such, depending on the assumptions made and the figures input, results can swing from a net disbenefit to a net benefit (de Jong, 2012; Newbold, 2012).

5.2 Attitudes and barriers to cycling

There are two mechanisms by which mandatory cycle helmet legislation can negatively impact on cycling rates. One is that current non-helmet-wearing cyclists are put off cycling because they have to wear a helmet; the other is that potential cyclists are put off cycling because they have to wear a helmet. For either of these reasons to actively discourage cycling, helmets must be seen as a primary barrier to cycling.

Haworth et al. (2010) and Olivier et al. (2013c) suggest that in Australia at least, this is not necessarily the case. Haworth et al. report a survey in Queensland that obtained free-response answers from infrequent or non-cyclists regarding reasons for not cycling for recreation, exercise or commuting. The most common reasons were health/ability to ride, time constraints, convenience and safety. Helmets and helmet legislation was apparently not mentioned, although "clothing" issues were mentioned by one leisure rider and 5% of commuters. Similarly, an online survey of 2,403 participants that examined constraints to cycling found that having to wear a helmet was the least important constraint for both men and women. Olivier et al. (2013c) meanwhile report that more recent surveys in Australia (2011 and 2013) suggest that infrastructure and safety concerns are much more common responses than having to wear a helmet.

While it appears that wearing a helmet when cycling is not necessarily a primary barrier to cycling, it must be acknowledged that wearing a helmet may be more of a barrier for adolescents (Christmas, Helman, Buttress, Newman & Hutchins, 2010). A qualitative study of cycling in Great Britain suggested that helmets were seen as something for children and that it is something children later grow out of (Christmas et al., 2010). Participants acknowledged that they felt safer when wearing a helmet (although the risk of being seriously injured or killed was not a common consideration for most cyclists) and helmets were not listed as a barrier or negative side of cycling (albeit there is obviously no mandatory requirement to wear a helmet in Great Britain). The most important barriers were instead other road users' behaviours and the volume and speed of traffic (Christmas et al., 2010).

5.3 Summary

Even if helmets do have an effect on head injury rates, it has been argued that it does not necessarily follow that legislation will have a public health benefit overall. Potential secondary effects, such as changes in cycling rates, which may affect individual and population health, have been suggested as potential mechanisms for this. Modelling studies and studies of mortality generally conclude that regular cyclists live longer because the health effects of cycling far outweigh the risk of crashes.

The evidence of the effect of mandatory cycle helmet legislation on the participation of children is mixed. International research indicates that an effect on cycling rates sometimes occurs, particularly in the first year after the introduction of compulsory helmet use. Dramatic figures reported from Australia in the early 1990's have not been replicated and may be explained by the timing and novelty of the legislation at this time, and further analyses of the data have suggested that some earlier analyses were flawed. The representativeness of these findings today could be questioned given the technological development of cycle helmets, cultural shifts towards cycling and cycling equipment, and attitudes towards helmets.

Based on the literature reviewed, the following conclusions can be made:

- Evidence of the impact of mandatory cycle helmet legislation is mixed. Legislation may not impact on cycling participation at all, although where it does, a temporary modest reduction in child cycling participation has been observed in other regions. However, it is not possible to say whether Jersey would experience this effect, in part because the earlier studies were some time ago and involved different cycling populations.
- Assuming only a temporary modest reduction in child cycle participation, it is reasonable to assume that mandatory cycle helmet legislation has no long-term effect on public health.

6 Jersey scrutiny review – local evidence

As part of the review on behalf of the States Greffe Scrutiny, members of the TRL team visited Jersey on 18th June 2014. The visit afforded the team the opportunity to meet key individuals, including from TTS and the Scrutiny Panel and listen to their views on the issues surrounding the compulsory wearing of cycle helmets. Further, over the course of the project, specific evidence has been sought to help qualify any comments and recommendations. This chapter summarises the key findings.

6.1 Background

Between 2003 and 2011, there were, on average, 45 road related deaths or serious injuries in Jersey annually. In 2013[2], there were 3 fatalities, 60 serious and 309 slightly injured casualties as a result of road traffic collisions; a total of 372, of which 51 were cyclists (13.7%). Further statistics are given in Section 6.4.

Only cycle helmets which conform to BS EN 1080 (children) and/or 1078 (adults) (i.e. meet the European standards) can be sold in Jersey.

Reassurances were given during the visit that there are enough cycle helmets available through local retailers in Jersey should compulsory helmet wearing be introduced, with costs starting at £10 to £15, and that retailers had sufficient training to ensure that the helmets sold fitted correctly.

Data is available from observational studies on cycle helmet wearing rates, which report 50% of adults and 86% of children were wearing a helmet in 2013. Among younger cyclists, females were more likely to wear a cycle helmet than males, although this margin is narrowing.

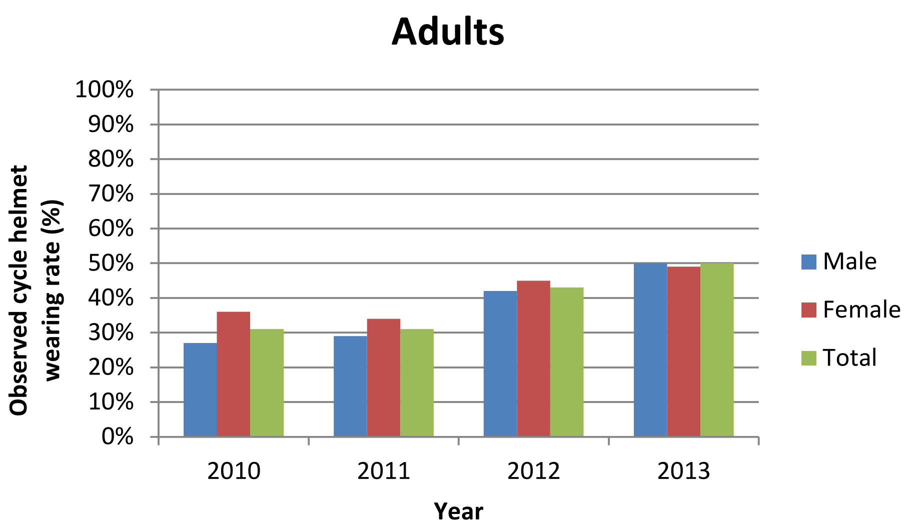


Figure 6-1: Adult observed cycle helmet wearing rates

2 http://jerseysaferoads.com/facts-stats/

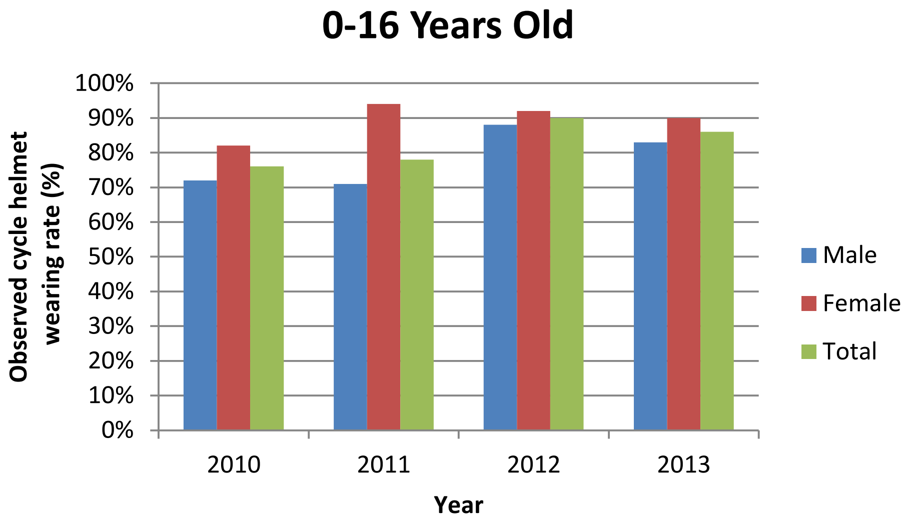


Figure 6-2: Child observed cycle helmet wearing rates

No specific data was found with respect to the amount of cycling that takes place on Jersey and therefore no segmentation was possible with respect to the types of journeys, ages of rider, gender or other factors.

Information provided indicated that of the 40 cyclists reported as attending the Jersey hospital with a head injury, only four had been riding on the road. It was not known whether or not these casualties had worn a helmet. However, it is a strong indicator that single cycle or fall collisions are a relatively common cause of cyclist head injury. This is important because these are the types of events where a cycle helmet would be most effective with regards to mitigating or preventing injury.

6.2 Road safety in Jersey and Infrastructure

Jersey has a draft Road Safety Strategy and is actively seeking ways to continuously improve road safety. Part of the ambition is to extend and improve the cycle network, which comprises a combination of dedicated cycle paths and a limited number of on road cycle lanes. Jersey also has 'green lanes' with a designated speed limit of 15 mph. These roads are believed to be popular with cyclists. The remaining roads in Jersey typically are rural and on the island the maximum permitted speed is 40 mph.

6.3 Scrutiny Panel

TRL attended a session of the Scrutiny Panel and listened to the varied concerns of all parties with respect to compulsory cycle helmet wearing. TRL took notes and contributed to the discussions to ensure as far as possible that the local context was captured in our review.

6.4 Enforcement

The following questions were asked to the States of Jersey Police (SOJP) and their responses are given in italics.

1. Are there any current roads policing problems with cycling/cyclists?

2013 The SOJP did see an increase in serious road collisions, some of which involved cyclist. This was catalyst for a campaign that was launched whereby we encouraged ALL road users to look out for each other and offer one another mutual respect. We are currently supporting efforts, led by TTS, with regards to Eco Safety and promoting safer cycling on the cycle tracks.

2. Do we envisage any problems policing this Law?
   Policing priorities are set on a monthly, weekly and daily basis, dependent on the nature of any given incident, through an intelligence led process that aligns threat and risk with operational deployment. This legislation and any methods of enforcement would be considered amongst other policing priorities, which include responding to concerns raised by the public. Operational priorities feed off of that process.

   The SOJP also recognise the value of public support and cooperation and so would look to use the law as an educational tool and make sure that any enforcement methods remain proportionate to the incident or offence. The absence of registration markings and registered keeper requirements, aligned to motor vehicles, will present some enforcement difficulties.

3. What kind of priority can we give to Policing this proposed Law?
   I think we follow the answer given for question 2. Priorities are set accordingly.

4. Are certain groups of cyclists (age, gender, any other characteristics) more frequently involved in cycling collisions?
   Essentially no – the stats below are fairly varied.

Cycle casualties 2013	Fatal	Serious	Slight	Grand Total
Male	**1**	**9**	**30**	**40**
11			1	1
13			1	1
14			2	2
15			1	1
17			1	1
19			1	1
20		1		1
21			1	1
22		1		1
24			1	1
29			1	1
31			1	1
33			2	2
34		1		1
35		1	1	2
36			1	1
37			1	1
40			1	1
41			1	1
42	1	1		2
43		1		1
46			2	2
47			1	1
48		1	1	2
53			1	1
54		1	1	2
57			1	1
59		1		1
61			1	1
63			2	2
64			1	1
66			1	1
Female		**5**	**5**	**10**
16			1	1
29			2	2
32			1	1
42		2		2
45		1		1
52		1		1
53		1		1
57			1	1
Unknown			**1**	**1**
47			1	1
Grand Total	**1**	**14**	**36**	**51**

Figure 6-3: Cyclist casualty age by injury severity

5. In your experience, how much cycling is for pleasure and how much is commuting (to and from work, school, clubs etc.)?

We do not keep data on this information but the SOJP can say that during a campaign led last year aimed at mutual respect, we spoke to at least 400 commuting cyclist during one day in order to offer advice on cycle safety and mutual respect for other road users.

6. Based on your experience and/or statistics, what are the current levels of cycling helmet wearing:
    a. for all cyclists?
    b. for younger cyclists (less than 14 years)?
    c. for adolescent cyclists (14-18 years)?

    These data is not held. Again from a speculative position on the same road safety campaign alluded to in question 5, approximately 50% of cyclist chose not to wear a helmet. On the same day however, a morning commuter took the time to purchase a helmet during her lunch acknowledging officers and her purchase on her return journey.
7. What mechanisms of enforcement and penalties would you suggest to ensure most cyclists choose to wear a helmet?

    Educational methods of enforcement would be appropriate whereby recommendations to attend on cycle safety courses would appear to be the most appropriate. Cycle safety is paramount here which is why we feel education is key.
8. Do you have any other comments regarding the compulsory cycle helmet wearing?

    It is realistic to say that any enforcement will need to sit amongst the many other priorities that the police need to attend to. Accordingly, that level of availability may vary in recognition of the very diverse demand placed on the SOJP.

The feedback from SOJP does not highlight any significant reasons why compulsory cycle helmet wearing should or should not be introduced. Discussion during the Scrutiny Panel (Section 6.3) on 18th June discussed the possibility of a civil offence and encouragement to buy/use cycle helmets which could be underpinned by fines.

The TRL review team discussed the opportunity to promote and publicise cycle helmet use as part of a co-ordinated road safety activity, perhaps in the springtime when cycling rates increase. This should involve a number of stakeholders, such as schools, police and road safety officials and aim to raise awareness of the benefits should compulsory cycle helmet wearing be introduced.

6.5 Summary of the Jersey experience

The first point to note is that cycle helmet wearing rates for children and young people (0-16 years old) are high (86% wearing rate in 2013) and appear to be increasing. This is important because the literature recognises that the effectiveness of compulsory cycle helmet wearing legislation is dependent, in part, on the existing attitudes and behaviours. Therefore Jersey is starting from a good base with a trend which indicates that cycle helmet wearing is an accepted part of riding for most young people.

The second important point relates to how effective helmets are likely to be at preventing injury in the event of a collision. Statistically it is likely that the majority of collisions in Jersey comprise single cycle incidents (falls etc.) or relatively low-speed impacts on dedicated cycle routes or low-speed roads. These are the environments where cycle helmets will be most effective at mitigating or preventing head injury.

The debate surrounding whether or not cycle helmet legislation will discourage cycling activity is important to address. Section 5.3 emphasises that legislation may not impact on cycling participation at all; and the most recent literature finds a worst case scenario of only a temporary modest reduction in child cycle participation. It is also important to note that the literature refers to different countries, which at the time had a much lower baseline cycle helmet wearing rate. Also the studies which highlight this potential reduction in cycling were originally conducted some 20 years ago (although many studies have been produced since re-analysing the data), when cycle helmet designs were very different to those currently available, in terms of materials, ventilation, coverage, comfort and even styling. It is not possible as part of this study to compare the road safety or cycle helmet wearing culture, but it is clear that the nature of the roads, and environment, including other vehicles, and therefore the types and nature of cycling are different between these studies and the Jersey experience today.

Consideration has been given to legislation and we recommend that it is coordinated with education and the already existing road safety and cycle safety programmes in Jersey.

On balance, given the voluntary increases in cycle helmet wearing rates in recent years for under 16s, it is reasonable to assume that compulsory cycle helmet wearing in Jersey, given all the factors mentioned above will at worst have a neutral effect on cycling participation and injury prevention. However, it is more likely to have a positive influence on reducing causalities and head injury severity, although there is insufficient data to quantify this at this time.

7 Summary and conclusions

This review has examined the potential implications of amendments to legislation proposed by the Minister for Transport and Technical Services in respect of the compulsory wearing of cycle helmets under the Draft Road Traffic (No. 60) (Jersey) Regulations 201-.

A desktop review of available reports and research from other jurisdictions with experience of similar legislation was undertaken. The work built on the early review of cycle helmet effectiveness carried out by Hynd et al. (2009), and extended the scope of topics considered. There were three broad questions which were addressed:

1. In the event of a collision, what is the influence of a cycle helmet on head injury protection?
2. What is the impact of cycle helmet legislation on injury rates?
3. What is the impact of cycle helmet legislation on cycling activity?

The evidence reviewed leads to the following answers to the research questions:

In the event of a collision, what is the influence of a cycle helmet on head injury protection?

In the event of a collision, the best evidence available suggests that helmets are effective in reducing injuries and injury severity. This conclusion is based on both laboratory test procedures using head-forms and paediatric human skulls, and on other study methods that examine the injury outcomes experienced by helmeted and non-helmeted cyclists in collisions.

What is the impact of cycle helmet legislation on injury rates?

The best evidence available suggests that cycle helmet legislation leads to reductions in cyclist injuries in all ages of cyclists; the plausible mechanism by which this benefit occurs is presumably that legislation tends to lead to increased wearing rates.

What is the impact of cycle helmet legislation on cycling activity?

Current evidence does not offer support for the assertion that cycle helmet legislation leads to large reductions in cycling participation that outweigh any potential injury reduction benefits through a corresponding reduction in health benefits. If reductions are observed they are likely to be small and short term.

Conclusions

On the basis of the evidence reviewed, we draw the following conclusions:

1. Legislation requiring the wearing of cycle helmets in Jersey can be expected to have a beneficial effect on the injury rates of those impacted by the legislation, especially in collisions that do not involve motor vehicles; most head injuries to younger cyclists in Jersey result from collisions that do not involve motor vehicles.

2. Such legislation seems unlikely to have a major impact on cycling activity in Jersey.

Other considerations

The authorities in Jersey will clearly be considering practical constraints to the legislation if it is introduced, including how enforcement will be handled, and how support might be put into place for cycling tourists and those who may be less able to procure a helmet for financial reasons. The evidence reviewed suggests that strong enforcement is likely to achieve higher wearing rates, but also that legislation alone is effective at increasing wearing rates.

As with any road safety law (should legislation be adopted) we recommend that attention is paid to ensuring that the public is aware of the legislation, and that publicity makes it clear that the new law is based on evidence and is designed to make cycling – an already healthy activity - a safer activity. In addition, Jersey authorities should continue to promote improvements to cycle safety in other ways if they wish to encourage more cycling; for example the enforcement of vehicle speeds, and attention to improving and advertising the existing cycling infrastructure should be continued.

Finally, we recommend that wearing rates and cycling activity rates are both monitored both before and after the legislation is enacted, in an appropriate and scientifically controlled evaluation framework that permits before-and-after comparisons of these outcomes (as well as injury rates). Such monitoring should also include surveys of attitudes towards cycling and cycle helmets. High quality monitoring and evaluation will enable firm conclusions to be drawn on the effects of the legislation, permitting on-going improvements to cycling and cycling safety provision Jersey.

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Jersey Scrutiny review:
Compulsory wearing of cycle helmets

TRL undertook an independent review of the literature relating to mandatory cycle helmet legislation on behalf of the Jersey Scrutiny Panel. This was undertaken to help inform the policy decision regarding compulsory wearing of cycle helmets under the Draft Road Traffic (No. 60) (Jersey) Regulations 201-. The review addressed three broad questions (i) in the event of a collision, what is the influence of a cycle helmet on head injury protection?; (ii) what is the impact of cycle helmet legislation on injury rates?; and (iii) what is the impact of cycle helmet legislation on cycling activity? The review concluded that legislation requiring the wearing of cycle helmets in Jersey can be expected to have a beneficial effect on the injury rates of those impacted by the legislation, especially in collisions that do not involve motor vehicles; most head injuries to younger cyclists in Jersey result from collisions that do not involve motor vehicles. Further, such legislation seems unlikely to have a major impact on cycling activity in Jersey.

TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

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