The effect of mandatory helmet laws on bicycle ridership and bicycle-related accidents: a rapid evidence review

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Executive Summary

Introduction

The purpose of this literature review is to inform Bicycle Network's position on mandatory bicycle helmet legislation (MHL) in Australia.

The scope of the consultancy work is a rapid review of available peer-reviewed literature to assist in identifying:

Q1. What are the effects of MHLs on bicycle ridership?

Q2. What are the effects of MHLs on the prevalence of bicycle-related accidents involving serious injury and/or fatality?

Methods

The author conducted two literature reviews for the project: one exploring links between MHLs and bicycle ridership (Q1); and another on the prevalence of bicycle related serious injuries/accidents (Q2). To meet the requirements of the project as efficiently as possible, the author:

- Conducted a review that was systematic and methodologically justifiable and that relied on specificity (rather than sensitivity) to deliver outputs within a short time frame.
- Used La Trobe library expertise to assist with developing search strategies.
- Used the Rayyan software package to assist with managing the literature identified.
- Limited searches to literature published in the last 38 years (since 1980), from countries where MHLs were implemented.

Five databases were systematically searched to identify literature for both review questions: Medline, EMBASE, Web of Science, SPORTDiscus and TRID. The identified literature underwent screening at title/abstract and full-text stages for eligibility in the review. Eligible studies underwent further critical appraisal to ensure biased studies were excluded ('risk-of-bias' assessment).

Results

The search terms identified 2523 studies across the five scientific databases (Web of Science: 446; EMBASE: 456; MEDLINE: 760; SPORTDiscus: 345; TRID: 516).

The search strategy for Q1 led to the following:

- Title and Abstract screening: 1589 studies
- Full Text screening: 64 studies
- Data extraction and risk-of-bias assessment: 10 studies
- Included studies: 5 articles/reports.

The search strategy for Q2 led to the following:

- Title and Abstract screening: 1589 studies
- Full Text screening: 148 studies
- Data extraction and risk-of-bias assessment: 20 studies
- Included studies: 13 studies

Findings

This review highlights the extremely complex nature of identifying causal relationships between MHLs and both bicycle ridership and the prevalence of serious bicycle-related accidents. The reasons for this complexity are due to issues with sampling, and inevitable biases and confounders that affect the reliability of the collected data. Moreover, it is difficult isolate the effects of MHLs from other external factors (e.g. population growth, enhancement of cycling infrastructure).

Q1: While there is some evidence that MHLs may not affect bicycle ridership, there is insufficient reliable evidence to draw robust conclusions. This is due to: (i) the small number of studies identified; (ii) conflicting evidence between studies; and (iii) issues of bias in the data collected.

Q2: Several high-quality studies suggest a protective effect of MHLs in mitigating serious injuries and fatality in Australia, however the results are mixed when international studies are also considered. Most studies in Canada and the US have concluded that MHLs have not been effective in reducing bicycle-related serious injury and fatality, while some studies suggest that the New Zealand MHL may have been effective.

Themes

The top 5 themes identified by the reviews are:

1. **A lack of reliable data on bicycle ridership –** While a small number of studies were found examining the relationship between MHLs and bicycle ridership, the methodologies and sampling techniques are highly susceptible to bias, and therefore causal links are difficult to establish.
2. **MHLs may protect against bicycle-related serious injury in Australia** – If the most reliable data and study designs are given proper emphasis (e.g. Walter et al, 2011; Olivier et al., 2013), the literature suggests an overall protective effect of the MHL on serious head injuries in Australia.
3. **The effectiveness of MHLs outside Australia are mixed** – Studies examining MHLs in Canada and the US reveal that they are generally ineffective at preventing serious injury (e.g. Dennis et al., 2009; Kett et al., 2016) and death (e.g. Wesson et al. 2007). However, some studies suggest that the New Zealand MHL may have decreased rates of serious head injury (Scuffham et al., 2000).
4. **Published data on bicycle-related injuries often carries bias** – The reliability of bicycle-related injury data is potentially compromised by biases such as uncontrolled confounding factors (e.g. pre-existing trends; Robinson, 2001), convenience sampling, and a lack of exposure-based data. There are also several shortcomings with commonly used data such as police reports and hospital admissions.
5. **Head injury rates commonly decline prior to MHL implementation –** In conjunction with theme 4, many studies have shown that bicycle-related injury data had already been in decline prior to MHLs being implemented both in Australia (Walter et al., 2011) and elsewhere (Dennis el al., 2009; Castle et al., 2012). These observations are likely to be the effects of coexisting road traffic safety initiatives, which may further bias injury data.
6. **MHLs alone will not protect persons riding bicycles against risks –** Most authors, either arguing for and against the effectiveness of MHLs, agree that helmets alone will not reduce the risks people are exposed to when riding bicycles. Consideration must also be given to driver-cyclist education, bicycle rider conspicuity, speed restrictions, and improved bicycle infrastructure.

Introduction

Background

On July 1st 1990, Victoria passed the world's first bicycle helmet legislation, a law requiring all bicycle riders and passengers using roads, footpaths and shared paths to wear a securely fitted, industry-approved bicycle helmet (National Road Transport Commission, 2012). By the end of 1992, all other Australian states had passed similar legislations. Since this time, bicycle helmet legislations have been passed in New Zealand, Canada and parts of the US (Dennis et al., 2009; Egberts et al., 2013; Oliver et al., 2014), and there are now discussions on whether such legislations should be passed in Germany and other parts of Europe (Juhra et al., 2010; Sieg, 2016).

The implementation of these mandatory helmet laws (MHLs) have sparked heated debate. Supporters of the legislation endorse the protective effect of helmets in mitigating serious head injuries and death. Opponents raise concerns about MHLs for a number of reasons: (i) the efficacy of bicycle helmets in crash situations is considered uncertain (Curnow, 2006); (ii) they infringe upon individual civil liberties (Clarke, 2012; Hooper & Spicer, 2012); (iii) they are associated with increased risks of rotational injuries (Curnow, 2003), and (iv) they encourage cyclists to undertake risky behavior (Robinson, 2006).

Determining the effectiveness of MHLs in promoting cyclist safety requires empirical evidence from studies with strong methodologies and reporting data with minimum bias. However, there are a number of issues that affect bicycle helmet studies, including: (i) publication and time-trend biases (Elvik, 2011; Robinson, 2001); (ii) over- and under-representation in certain types of population data (e.g. police records; Hynd, Cuerden, Reid, & Adams, 2011); and (iii) flaws in certain study designs (Olivier & Radun, 2017; Olivier et al., 2014). Moreover, assessing the role of bicycle helmets (and MHLs) in cycle safety may be subject to a wide range of confounding variables including, but not limited to: rider age, rider gender, conspicuity (e.g. use of hi-vis gear), road and cycling infrastructure, region-specific road rules, collision speeds, time of day, and alcohol consumption. Overall, there exists a wide range of complexities in determining scientifically whether MHLs effectively contribute to the safety of bicycle riders.

Nature of the review

The scope of this consultancy work is a rapid evidence review of available peer-reviewed literature to inform Bicycle Network's position on mandatory helmet legislation (MHL) in Australia.

This review does not attempt to capture and describe the broad range of issues relating to the effectiveness of MHLs. To adequately answer this broad question, several systematic reviews would be required on topics such as: the determinants of bicycle-related accidents; helmet efficacy during accidents; helmet wearing rates and legislation compliance; and the cost-effectiveness of MHLs. Rather, the current review will address two of the most salient questions:

Q1: What are the effects of helmet laws on bicycle ridership?

It is evident that a communities' use of bicycles will carry health, economic and sustainability benefits. Thus, the first question focuses on whether there is a causal relationship between bicycle helmet legislation and the degree of ridership in the community, thus identifying any deterrent effects of the former. Here, 'ridership' is defined as the prevalence of persons engaged in the riding of bicycles for commuting or recreational purposes.

Q2: What are the effects of helmet laws on the prevalence of bicycle-related serious injuries and fatalities?

This question aims to address the efficacy of helmet legislation in mitigating bicycle accidents involving serious injury or death. 'Serious injury' is defined here as injuries requiring detainment in hospital, particularly involving the head (e.g. traumatic brain injury).

Methods

Project plan: Rapid review

This project is a rapid review, rather than a thorough exploration of the literature. A rapid review is not a full systematic review, but strategic decision-making in the planning phase sets out parameters that limit the review to project what is manageable within set timelines.

Whilst rapid reviews do aim for rigour and a systematic methodology, they may be more amenable to bias than other types of reviews, an inevitable by-product of the speed at which they are produced. To control for this possibility, the author has documented the methodology in considerable detail. In addition, the search terms that produced this review's data is stated below, and the list of studies excluded at the full-text screening stage will both be included (Appendix 2).

To meet the requirements of the project as efficiently as possible, the author has:

- Conducted a review that is systematic and methodologically justifiable and that relies on specificity (rather than sensitivity) to deliver outputs within a short time frame.
- Consulted La Trobe University research librarians to assist with developing search strategies.
- Used the Rayyan[1] software package to assist with managing the literature identified.

PICO, PRISMA and search strategy

The following table sets out a Population / Intervention / Comparison / Outcomes (PICO) framework for the review questions. A PICO framework is helpful in identifying the search terms to be used, and the appropriate inclusion/exclusion criteria for screening.

QUESTION	POPULATION	INTERVENTION / EXPOSURE	COMPARISON	OUTCOMES
QUESTION 1	People who ride bicycles (over 16 years)	Mandatory bicycle helmet laws	Not applicable	Bicycle ridership
QUESTION 2	People who ride bicycles (over 16 years)	Mandatory bicycle helmet laws	Not applicable	Bicycle-related accidents involving serious injury or fatality

To identify literature relevant to both questions of the review, the following search terms were used to query scientific databases:

```
1  ((helmet*) AND (bike* OR bicycl* OR cycl* OR 'rider*' OR 'bike rider*' OR
   'cycl* rider*' OR 'road rule*' OR law* OR mandatory OR standard* OR
   legislat* OR 'Australian road rule'))
2  Accidents, Traffic/ or Bicycling/ or Exercise/ or Recreation/ or Sports/
3  1 and 2
4  limit 3 to (english language and yr="1980 - 2017" and ("all adult (19 plus
   years)" or "adolescent (13 to 18 years)"))
```

Systematic searches of peer-reviewed literature were queried in five key scientific databases: Web of Science, EMBASE, MEDLINE, SPORTDiscus and TRID. These searches collected literature between the years 1980-2017, in order to provide sufficient data across pre- and post-MHL periods.

[1] Rayyan QCRI (https://rayyan.qcri.org)

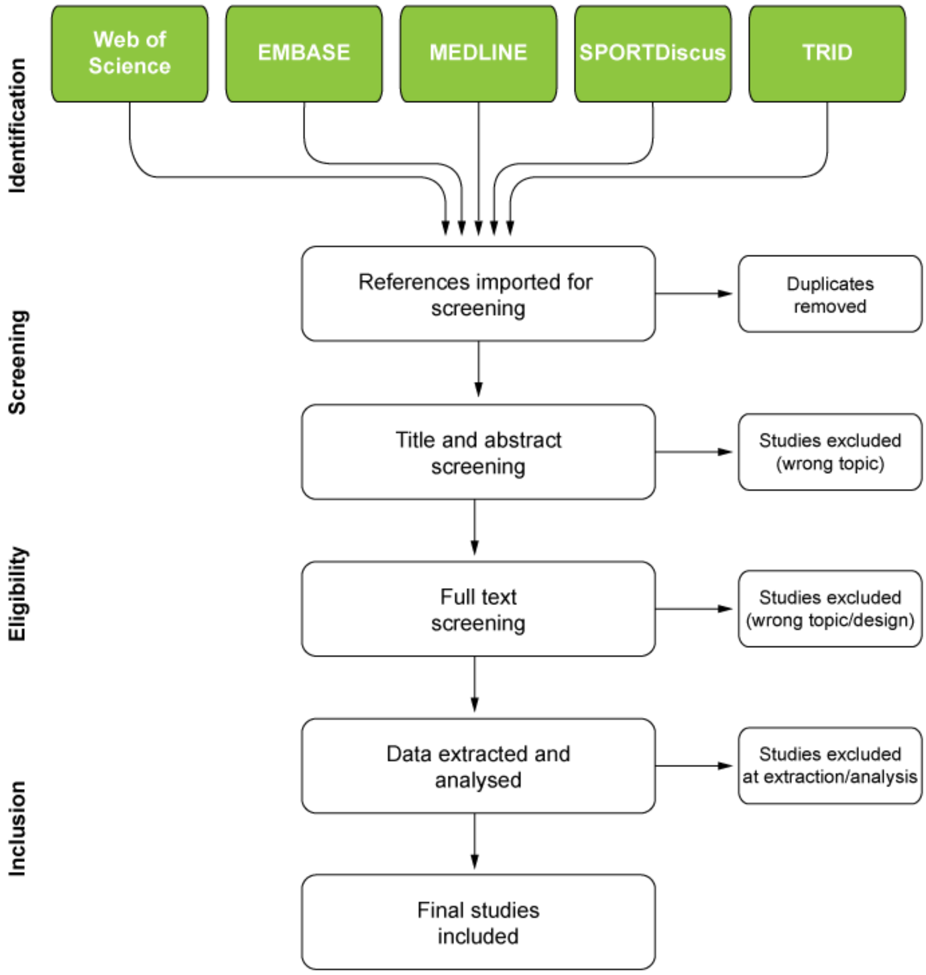

Figure 1. PRISMA diagram outlining the key processes for identifying studies for inclusion in the review.

A PRISMA diagram outlining the workflow is presented in Figure 1. Once literature was exported from the five databases and duplicates were removed, all studies underwent a title-abstract screening against predefined inclusion/exclusion criteria (refer next page). Examples of study designs eligible for inclusion were interrupted time series, case-control studies, and quasi-experimental studies. Secondary analyses of previously published data were considered where a causal link between MHLs and bicycle use/serious injuries was being established; or the authors were commenting on the validity of previous interpretations. General epidemiological studies were not considered, as causal links between MHLs and bicycle use/serious injuries are not a primary outcome. Studies included at the title-abstract screening stage underwent a subsequent full-text screen to determine their eligibility for the review. Eligible studies proceeded to data extraction and underwent a systematic critical appraisal using the Joanna Briggs Institute checklist, an internationally endorsed assessment of study bias (Appendices 3-5).

Inclusion/exclusion criteria

The following criteria were used to determine the eligibility of identified literature for addressing each of the research questions. All literature identified by the search strategy underwent screening against the listed Q1 and Q2 criteria.

Q1: What are the effects of bicycle helmet road rules on ridership?

Inclusion criteria

- Primary articles, systematic reviews and meta-analyses
- Studies reporting on helmet use by people riding bicycles
- Studies reporting on a relationship between mandatory helmet laws and bicycle use/participation/exposure
- Study populations using bicycles for recreation and/or transport purposes
- Studies reporting data on persons over 16 years of age
- Studies published between January 1980 and December 2017
- Studies published in English

Exclusion criteria

- Studies reporting on helmets associated with motorcycles, motorbikes, electric bikes, mopeds and scooters, skateboards, inline skates, and sports
- Study populations using bicycles for competitive, extreme (e.g. mountain-bike, BMX) purposes; or participating in bicycle-related events
- Studies reporting on interventions to increase helmet usage and rider attitudes about helmets
- Studies reporting on helmet efficacy and performance, advancements of helmet technology and helmet safety materials testing
- Observational studies reporting on legislation compliance and/or general helmet use by bicycle riders, or studies reporting determinants for helmet use
- Studies reporting data on persons under 16 years of age

Q2: What are the effects of bicycle helmets (and road rules) on the prevalence of bicycle-related accidents involving serious injury and/or fatality?

Inclusion criteria

- Primary articles, systematic reviews and meta-analyses
- Studies reporting on helmet use by people riding bicycles
- Studies reporting on a relationship between helmet laws and the prevalence of bicycle-related accidents
- Study populations using bicycles for recreation and/or transport purposes
- Studies reporting data on persons over 16 years of age
- Studies published between January 1980 and December 2017
- Studies published in English

Exclusion criteria

- Studies reporting on helmets associated with motorcycles, motorbikes, electric bikes, mopeds and scooters, skateboards, inline skates, and sports
- Study populations using bicycles for competitive, extreme (e.g. mountain-bike, BMX) purposes; or participating in bicycle-related events
- Studies reporting on helmet efficacy and performance, advancements of helmet technology and helmet safety materials testing
- Studies reporting on accidents and/or deaths/injuries not caused by cycling
- Observational studies reporting on legislation compliance and/or general helmet use by bicycle riders, or studies reporting determinants for helmet use
- Studies reporting on bicycle-related accidents and/or deaths/injuries where drugs/alcohol were used
- Studies reporting data on persons under 16 years of age

Results

All results for the literature capture are presented in Figure 2. The search strategy identified 1589 unique studies of potential relevance to both study questions. The literature pool then underwent title-abstract screening, from which 64 and 148 studies were deemed relevant for questions 1 and 2, respectively. Subsequent full-text screening further refined the number of eligible studies to 10 (Q1) and 20 (Q2).

Risk of bias assessments using JBI Critical Appraisal checklists resulted in a further 11 exclusions at the data extraction stage. Overall, 19 studies (Q1: 5; Q2: 13) were identified as relevant to the review questions. Summaries of the included and excluded studies are presented in Appendices 1 and 2, respectively. Outcomes for the risk-of-bias assessments can be found in Appendix 5.

The included literature comprised studies from Australia, Canada, USA, and New Zealand. Most of these studies were quasi-experimental studies, often using interrupted time series data to draw conclusions of the effects of helmet legislation over time. The literature search also identified one systematic review, which was relevant to both research questions: Macpherson and Spinks (2008) aimed to evaluate the effect of MHLs worldwide on bicycle-related head injuries, helmet use, and cycle use by systematically reviewing literature prior to 2008. This previous systematic review had a slightly different scope than the current review, and all included studies were captured in the current review's search strategy. Moreover, the current review builds on Macpherson and Spinks' findings by reviewing an additional decade of potentially relevant studies. The decision was made to include Macpherson and Spinks' 2008 study in the current review to assess their findings, and so that the authors' interpretations could be analysed and represented.

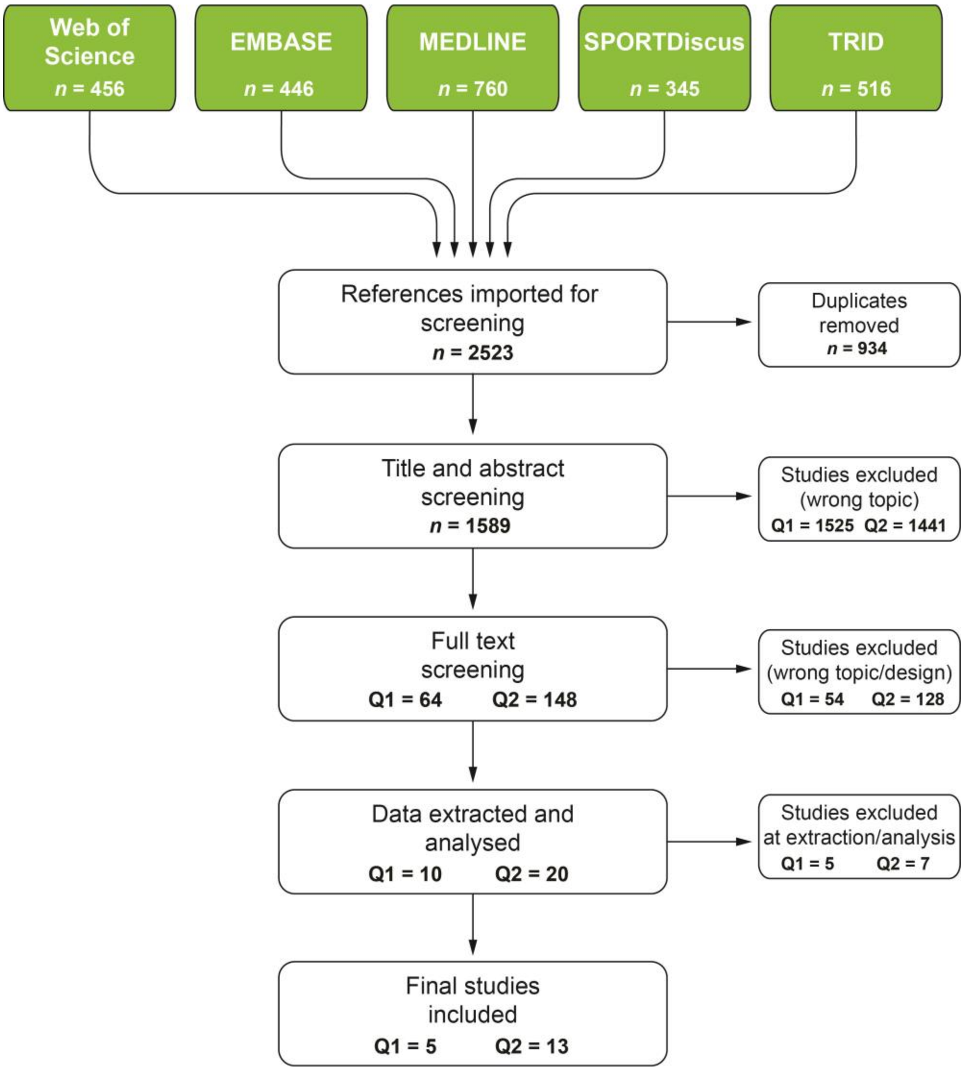

Figure 2. Summary of included/excluded studies at each reporting stage of the review.

Summary of included studies

Q1: What are the effects of helmet laws on bicycle ridership?

Author	Aim	Study design	Sample size	Results	Implications
de Jong (2012) **Country** Australia **Helmet legislations** All	Evaluate whether MHLs deliver net societal health benefits using quantitative modelling.	Secondary analysis **Data collection** Primary studies on bicycle-related health benefits; cycling count data (e.g. Robinson 1996; 2001; 2005); and helmet effectiveness. **Analysis** Quantitative modelling of helmet efficacy, cycling use and health benefit data to derive the net benefit:cost ratio for cycling under an MHL.	n/a **Age (mean)** n/a **Male (%)** n/a	In jurisdictions where cycling is safe (e.g. the Netherlands), helmet laws are likely to have a large unintended negative health impact. In jurisdictions where cycling is relatively unsafe (e.g. Great Britain), helmets will do little to make it safer and a helmet law, under relatively extreme assumptions, may make a small positive contribution to net societal health.	Helmet legislation may result in negative net health benefits, related to decreases in cycling use. **Limitations** Risk compensation and substituting exercise may bias the benefit/cost ratio up and down, respectively (Newbold, 2012). It may be the case that those giving up cycling are not representative: they may be more accident prone, less susceptible to the health stimulus, or more inclined to substitute cycling with other exercise activities. **Note:** This study was commented on by Newbold (2012), who found that mandatory bicycle helmet laws had positive net public health benefits there when modeled against US cycling statistics. The author also responded to this comment (de Jong, 2012b).
Author Dennis et al (2009) **Country** Canada **Helmet legislation** >18 years: New Brunswick, British Columbia, Nova Scotia, Prince	**Aim** Examine association between MHLs in Canada and bicycle helmet use in youth and adults, and compare bicycle ridership before and after implementation of legislation.	**Study design** Interrupted time series (quasi-experimental) **Data collection** Cross-sectional survey data (Canadian Community Health Survey) between 2000-01, 2003, 2005 and 2007.	**Sample size** All ages MHL (sample): 524 No MHL (control): 397 **Age (mean)** n/a **Male (%)**	**Results** Among adults in Prince Edward Island (PEI; sample), the prevalence of bicycle use was 17.6% in 2001 versus 19.0% in 2003 (post-MHL). The mean number of times cycled decreased from 20.0 in 2001 to 17.3 in 2003.	**Implications** Helmet legislation is not associated with changes in ridership. **Limitations** n/a

Edward Island <18 years: Ontario and Alberta		**Analysis** Student t-test between provinces with MHL (sample) and those without (control)	39.9%	Following implementation of legislation in PEI and Alberta, recreational and commuting bicycle use remained unchanged among youth and adults.	
Author Macpherson and Spinks (2008) **Country** Australia **Helmet legislation** All	**Aim** Review the available literature assessing effects of MHLs on bicycle-related head injuries, helmet use, and bicycle use.	**Study design** Systematic review **Data collection** Searches in Cochrane Injuries Group's specialized register, CENTRAL, MEDLINE, EMBASE, TRANSPORT, CINAHL, National Research Register, Clinical Trials and Controlled Trials metaRegister, Zetoc, SPECTR, HealthPromis and Bibliomap. Two authors independently assessed studies against the inclusion criteria. **Analysis** Data extracted independently by two authors using standardized data extraction forms. Critical appraisal performed.	**Sample size** n/a **Age (mean)** n/a **Male (%)** n/a	**Results** There were no included studies reporting change in bicycle use or other adverse consequences of legislation.	**Implications** There is a paucity of reliable data on possible declines in bicycle use as a result of MHLs worldwide. **Limitations** n/a
Author Olivier et al (2016) **Country** Australia **Helmet legislations** Australian Road Rule (all states, all	**Aim** Evaluate whether MHLs lead to decreases in cycle use in Australia and elsewhere.	**Study design** Review, secondary analysis **Data collection** Cycling participation data (Australian Bicycle Council, South Australian Department of Transport; Traffic Board of Western Australia); survey responses	**Sample size** n/a **Age (mean)** n/a **Male (%)** n/a	**Results** Stratified random sampling surveys estimate cycling frequencies before and after the introduction of MHL. The results of these surveys suggest that there was no real impact on cycling frequencies following MHL implementation.	**Implications** When the best study designs and data quality are considered (e.g. random stratified surveys), the best evidence suggests that the Australian MHL has never been a major barrier to cycling. **Limitations** Cycling frequencies were not

ages)		(National Heart Foundation of Australia). **Analysis** n/a			estimated for NSW, Queensland or Victoria.
Author Rissel and Wen (2011) **Country** Australia **Helmet legislation** Australian Road Rule (NSW)	**Aim** Assess if people in Sydney would cycle more if helmets were not required, and how often they would wear helmets.	**Study design** Cross-sectional, qualitative **Data collection** Computer-assisted telephone interviewing propensity to cycle if helmets were not required, how often respondents who cycled would cycle without a helmet; and opinions on compulsory wearing of bicycle helmets. Frequency of cycling, and demographic questions were also assessed. **Analysis** Multiple logistic regression to model outcomes (would ride without a helmet if allowed, how often would ride without a helmet, and support of mandatory legislation) and calculate adjusted odd s ratios. Weighted to Australian population.	**Sample size** 600 **Age (%)** 16-24 yrs: 17.5% 25-39 yrs: 29.2% 40-54 yrs: 25.4% 55+ yrs: 27.9% **Male** 49%	**Results** One in five (22.6%, 95% CI 18.8-26.4%) respondents said they would cycle more if they did not have to wear a helmet. Almost half (47.6%) of respondents said they would never ride without a helmet, 14.4% said 'all the time', 30.4% said 'some of the time' and the rest were not sure. One third (32.7%, 95% CI 28.5-37.0%) of respondents did not support mandatory helmet legislation.	**Implications** Cycling participation may increase if helmet legislation was repealed. **Limitations** Quota sampling may have introduced potential for bias towards those people more likely to be at home and agree to participate in market research surveys. The study is qualitative; the data are opinions rather than quantifiable actions.

Q2: What are the effects of a helmet laws on the prevalence of bicycle-related serious injuries and fatalities?

Author	Aim	Study design	Sample size	Results	Conclusions
Castle et al (2012) **Country** USA (California) **Helmet legislation** <18 years	Determine the effect of a Californian MHL on injury patterns in bicyclists in Los Angeles County.	Retrospective interrupted time series **Data collection** Trauma patient data between 1992-2009 (Los Angeles County Trauma and Emergency Medicine Data System)	1684 patients **Number of controls** None **Age (%)** <1: 0.3% 2-5y: 9% 6-9 y: 26% 10-14 y: 45% 15-17 y: 16% **Male (%)** 80%	While the overall percentage of helmeted patients increased between the pre-legislation and post-legislation periods, the percentage of helmeted bicyclists remained variable from year-to-year, with 59 (67%) injured riders sustaining head injuries in 1992–1993, and 1006 (63%) sustaining head injuries from 1994–2009 (P = 0.35).	The Californian MHL did not increase rates of helmet use, nor decrease rates of head injury in Los Angeles County. California helmet legislation has not been effective in decreasing head injuries. **Limitations** No control group (e.g. non-head injuries)

Author	Aim	Study design	Sample size	Results	Implications
Dennis et al (2013) **Country** Canada **Helmet legislation** >18 years: New Brunswick, British Columbia, Nova Scotia, Prince Edward Island <18 years: Ontario and Alberta	Investigate associations between MHLs and admissions to hospital for cycling related head injuries among young people and adults in Canada.	Quasi-experimental (interrupted time series) with control **Data collection** Hospital admission data across Canada between 1994-2008 (National Trauma Registry Minimum Data Set) **Analysis** Change (%) in annual rates of hospital admissions Poisson regression analysis model of head injury related admissions vs all admissions	19732 head-injured cyclists (sample) 66716 injured cyclists (control) **Age (mean)** n/a **Male (%)** 75%	Hospital admission rates for cycling related head injuries decreased by 54% in provinces with MHL; and 33.2% in provinces without MHL. Among adults (18+) the rate of total hospital admissions for cycling related injuries increased between 1994 and 2003, but this increase was not statistically significant. The authors did not detect statistically significant effects of MHLs on rates of hospital admissions for cycling related head injuries per total admissions in the years after legislation was implemented.	Reductions in hospital admission rates were greater in provinces with an MHL, however injury rates were decreasing prior to MHL implementation, and rates of decline did not vary significantly post-legislation. No significant effect of MHL. **Limitations** No data on emergency room visits, or cyclist deaths before reaching hospital.

Author	Aim	Study design	Sample size	Results	Conclusions
Ji et al (2006) **Country** USA **Helmet legislation** <18 years	Evaluate effects of a Californian MHL on bicycle-related head injuries in San Diego County by measuring reductions in bicycle-related head injuries (and increases in helmet use).	Ecological trend **Data collection** Trauma Registry data between 1992 and 1996 (San Diego County Trauma Registry) **Analysis** Chi-square test to evaluate bivariate associations. Logistic regression analysis to assess trends over time for helmet use and for serious head injury	1116 patients (Children: n=510; Adults: n=606) **Number of controls** n/a **Age (%)** **Male (%)** 82.1%	Pre-law and post-law helmet use in sample were 13.2 and 31.7% (respectively). Helmet use increased by ~43% per year Children (<18 years) comprised 41.9% of all serious head injuries; adults (>18 years) comprised the remaining 58.1%. No statistically significant trend for serious head injury pre- and post-MHL.	While the Californian MHL has significantly increased helmet use among children as well as in adults, the study did not confirm whether helmet legislation alone significantly reduced head injury rates in San Diego County during the study period. **Limitations** Trauma registry data biased towards more serious injuries. Partial missing data for helmet use.

Author	Aim	Study design	Sample size	Results	Implications
Kett et al (2016) **Country** USA **Helmet legislation** All ages (Seattle, King County)	Examine variations in helmet-preventable injuries in Seattle (MHL est. 2003) and comparing with data in King County outside of Seattle (MHL est. 1994).	Interrupted time series (quasi-experimental) **Data collection** Trauma data between 2002-2010 (Washington State Trauma Registry). Adjusted for location, age, injury location (i.e. head) and injury severity. **Analysis** Odds ratio calculation (helmet use vs head trauma), incidence rate ratios (pre- and post-legislation).	Seattle (sample): 547 injured bicyclists King County (control): 767 injured bicyclists **Age (mean)** n/a **Male (%)** n/a	No significant variation in bicyclists admitted to hospital and treated for head injuries in either Seattle (37.9 vs 40.2 %) nor in the rest of King County (30.7 vs 31.4 %). Bicycle-related major head trauma, as a proportion of all bicycle-related head trauma, decreased significantly in Seattle (83.9 vs 64.9 %), but not in King County (64.4 vs 57.6 %). Results demonstrate a decrease in the severity of bicycle-related TBI since implementation of the law, as well as a decrease in the number of fatalities	MHLs may have contributed significantly to injury prevention in Seattle and throughout King County. Increased uptake of helmet use and decreased major head injuries suggest helmet laws may have been effective in decreasing head injuries severity. **Limitations** No data on miles traveled by bicyclists or other exposure methods.

Author	Aim	Study design	Sample size	Results	Implications
Macpherson and Spinks (2008) **Country** Australia **Helmet legislations** All	Review available literature assessing the effect of MHLs on bicycle-related head injuries and helmet use.	Systematic review **Data collection** Searches in Cochrane Injuries Group's specialised register, CENTRAL, MEDLINE, EMBASE, TRANSPORT, CINAHL, National Research Register, Clinical Trials and Controlled Trials metaRegister, Zetoc, SPECTR, HealthPromis and Bibliomap. Two authors independently assessed studies against inclusion criteria. **Analysis** Data extracted independently by two authors using standardized data extraction forms.	n/a **Age (mean)** n/a **Male (%)** n/a	Six studies, all with non-randomised, controlled before and after study designs met inclusion criteria. All included studies related to cyclists under 18 years. Authors identified one study involving cyclist injuries in 16-18 year olds (i.e. meeting inclusion criteria of current review) by Wesson et al (2008). Both have been included in the current review and are described elsewhere.	There is a paucity of reliable data related to the effects of bicycle helmet legislations on the prevalence of bicycle-related injuries. **Limitations** n/a
Author Olivier et al (2013) **Country** Australia **Helmet legislation** Australian Road Rules (NSW)	**Aim** Investigate long-term trends in cyclist head (sample) and arm (control) injuries over the period 1991–2010; to determine ongoing effects of mandatory helmet legislation (MHL) on head injuries.	**Study design** Quasi-experimental with case-control component **Data collection** Hospital data for cycling injuries in NSW between 1991-2010 (Admitted Patients Data Collection) **Analysis** Log-linear regression models	**Sample size** Sample: *n*= 15227 Control: *n*= 24772 **Age (mean)** n/a **Male (%)** n/a	**Results** Arm injuries (control) were higher than head injuries throughout the study period; and increasing at a much slower rate. All models reveal increasing divergence between arm and head injuries in the post-MHL period for adults, but no significant trend for children.	**Implications** Study suggests a beneficial effect of MHL in reducing head injuries in bicycle riders. Increase in arm injuries likely reflects increased ridership. Head injuries likely associated with motor-vehicle collisions; highlights needs for better infrastructure and rider-driver education to reduce risk.
Author Povey et al (1999) **Country**	**Aim** Assess effects of helmet wearing on hospitalised head injuries between 1990 and 1996, using	**Study design** Interrupted time series (quasi-experimental)	**Sample size** n/a **Age (mean)**	**Results** Cyclist head injuries decreased with increasing helmet wearing rates for each	**Implications** The increase in the cycle helmet wearing rate reduced the risk of head injury in cycling

New Zealand **Helmet legislation** All ages	cyclist limb injuries as a measure of exposure to risks of cycling trauma.	**Data collection** Hospital admission data between 1990-1996 (New Zealand Health Information Service). Helmet use measured by national surveys (Land Transport Safety Authority) **Analysis** Log-linear modelling of helmet use versus (head and limb) injuries. Limb injuries used as control group and measure of exposure to cycling risk. Motor-vehicle and non-motor vehicle crashes analysed separately. Age groups analysed separately. Severity of head injuries also investigated by analyzing abbreviated injury scale (AIS) values of head injuries over time.	n/a **Male (%)** n/a	age group, most strongly among children. Increases in helmet wearing rates of 5% (i.e. from 90 to 95%, or 80 to 85%), at a given exposure level, correspond to percentage decreases in the number of head injured cyclists of 10.2, 5.3 and 3.2% for primary, secondary and adult cyclists, respectively. Increases in helmet wearing, associated with MHL implementation in 1994, reduced head injuries by between 24 and 32% in non-motor vehicle crashes, and by 20% in motor vehicle crashes. No strong evidence for variations in injury severity over the study period.	accidents. **Limitations** No detail on time series effects.
Author Robinson (1996) **Country** Australia **Helmet legislations** All ages	**Aim** Compare observed changes in cyclist head injury with pre-MHL predictions; and to compare cyclist injuries with the amount of cycling.	**Study design** Secondary analysis **Data collection** Public hospital admissions of adult and child cyclists in NSW, and all public hospital admissions for cycling and pedestrian injuries in Victoria. Helmet wearing and bicycle counts from RTA, VicRoads and Monash Uni Accident Research reports (Sullivan, 1990; Finch et al, 1993;	**Sample size** n/a **Age (mean)** n/a **Male (%)** n/a	**Results** In the first year of the Victorian MHL, the reduction in cyclists counted was four times greater than the increase in cyclists wearing helmets. While estimates indicate a reduced risk of head injury for helmeted cyclists, the percentage of accident victims with head injuries was also declining for other road users such as pedestrians.	**Implications** Decreases in numbers of cyclists four times the increases in numbers wearing helmets strongly suggests a sudden and sustained reduction in cycle use immediately after the helmet law was introduced. The most significant effect of the law was not its effect on head injuries but on numbers of cyclists. 'Risk compensation' (i.e. protected cyclists undertake

		Smith and Millthorpe 1993) **Analysis** The effect of helmets for cyclists involved in an accident was obtained by comparing observed changes in helmet wearing with pre and post law percentages of head injured cyclists. To reduce the effect of trends unrelated to helmet wearing, data for the year immediately prior to the law were compared with the first post law year for all cyclists.		The decrease in numbers of cyclists was at least as large as the decrease in numbers of head injuries and larger than the total decrease in injuries.	riskier behaviours) may be associated with the persistence of injuries (despite decreasing cyclist counts) post-MHL. **Limitations** Increased helmet wearing may not have coincided exactly with the start of the law.
Author Robinson (2001) **Country** New Zealand **Helmet legislations** All ages	**Aim** Respond to conclusions made by Povey et al (1999) on their observed reductions in bicycle-related head injuries following New Zealand MHL.	**Study design** Secondary analysis **Data collection** Head injury and helmet use data from Povey et al (1999) **Analysis** Cross comparison of head injury data and helmet-wearing rates over time.	**Sample size** n/a **Age (mean)** n/a **Male (%)** n/a	**Results** When helmet use and head injury rates are projected concomitantly, the substantial increase in helmet wearing is not met with associated injury decreases. Robinson criticizes Povey et al for not fitting a time trend to their model, which may have captured the helmet effect more effectively. If the data contain no time trends, every 1% increase in voluntary helmet wearing before the law was 15 times more effective in reducing head injuries than a 1% increase due to the law.	**Implications** Time series studies are susceptible to time trend bias, which bears significant implication for the outcomes of bicycle helmet legislation studies. A reduction in head injury due to increased helmet wearing is plausible only if the change in head injury coincides with the increase in helmet wearing. **Limitations** n/a
Author	**Aim**	**Study design**	**Sample size**	**Results**	**Implications**

Scuffham et al (2000) **Country** New Zealand **Helmet legislations** All ages	Examine the effect of helmet wearing and New Zealand's MHL on hospital admission rates for head injuries to cyclists injured on public roads.	Quasi-experimental **Data collection** Helmet wearing rates measured by national observational surveys (Land Transport Safety Authority) Hospitalization data to measure cycle-related injuries between 1988-1996 (New Zealand Health Information Service). Controlled for non-cyclist head injuries. **Analysis** Negative binomial regression modelling. Control trials for head vs non-head injuries, and cyclist vs non-cyclist head injuries.	n/a **Age (mean)** n/a **Male (%)** n/a	Helmet wearing rates in New Zealand was associated with decreased head injury across different age groups and head injury types (e.g. lacerations, fracture, brain injury). Changes in admission rates for head injury to cyclists were directly related to changes in admission rates for head injury to non-cyclists. The age groups with the lowest pre-law helmet wearing rates benefited the most from the introduction of the helmet wearing law.	Helmet wearing significantly reduces head injuries to cyclists. New Zealand's MHL is an effective road safety intervention that averted 139 head injuries and lead to a 19% reduction in cyclist head injuries to cyclists over its first 3 years. **Limitations** Lack of an accurate measure for exposure of cyclists to head injury Complications with stratifying hospital admissions involving multiple head and non-head injuries.

Author	**Aim**	**Study design**	**Sample size**	**Results**	**Implications**
Teschke et al (2015) **Country** Canada **Helmet legislations** British Columbia, New Brunswick, Nova Scotia and Prince Edward Island (All ages) Alberta, Ontario (<18 years)	Calculate exposure-based bicycling hospitalisation rates in Canadian jurisdictions with different helmet legislation and bicycling mode shares	Quasi-experimental **Data collection** Hospitalisation data for bicycle-related injuries across 10 body regions (e.g. head, arm) from 2006-2011 (Discharge Abstract Database). Bicycle trip data from 2006-2011 (Canadian Community Health Survey) **Analysis**	3690 hospitalisations 593 million annual cycling trips **Age (mean)** n/a **Male (%)** n/a	Hospitalization rate of 622 per 100 million trips over a study period for cyclists >12 years. Females had lower hospitalisation rates than males. Lower rates of traffic-related injuries were associated with higher cycling mode shares Helmet legislation was not associated with hospitalisation rates for brain,	Factors other than helmet laws have more influence on injury rates. Lower hospitalisation rates and higher cycling mode shares together suggest a "safety-in-numbers" associated. Bicycling infrastructure physically separated from traffic or routed along quiet streets may be associated with a lower relative risk of injury. **Limitations**

		Hospital stays and bicycling trip data stratified by jurisdiction, sex, age group, injury cause and injured body region, and subsequently integrated to calculate hospitalization rates for different body regions. Linear and multiple regression models used to examine associations between (i) hospitalization rates, (ii) body regions, and (iii) mode share/helmet legislations across 11 Canadian jurisdictions.		head, scalp, skull, face or neck injuries.	Possible bias in cycling survey data (Health Survey does not ask for explicit cycle trip data) Hospital data biased towards serious cycling injuries. Integrated hosiptalisation/cycling trip data did not match perfectly on the temporal scale, due to differences in their data collection times.
Author	**Aim**	**Study design**	**Sample size**	**Results**	**Implications**
Walter et al (2011) **Country** Australia **Helmet legislation** Australian Road Rule (all ages)	Examine effects of MHLs on cyclist head injuries by identifying differential changes in head/limb injury rates following MHL implementation.	Quasi-experimental (time series) **Data collection** Traffic accident data ±18 months of MHL implementation to assess helmet compliance and seasonal accident trends (Traffic Accident Database System) Hospital admissions data between 1988-1997 (NSW Admitted Patients Data Collection) to assess head vs limb injuries **Analysis** Log-linear (negative binomial) regression analysis of time, injury and legislation covariates.	Head injuries: 2154 Arm injuries: 2221 **Leg injuries:** 1196 **Age (mean)** n/a **Male (%)** n/a	All estimated trends in injury rates showed a moderate decrease prior to MHL implementation (with exception of pedestrian arm injuries). Mean annual percentage decreases in injury rates between 4.5-23.6% per year. Head injury rates decreased significantly more than limb injury rates at the time of legislation among cyclists (sample) but not pedestrians (control). Regression models exhibit decreasing trends in injury rates prior to legislation, an increasing trend thereafter and a drop in rates at the time the MHL was enacted.	Data implies a positive effect of MHLs on cyclist head injuries. Pre-MHL decreasing trends may have been driven by broader road safety improvements related to enforcement of motor vehicle laws and promotion of safer road use. **Limitations** Assumptions made about helmet wearing rates. Confounding variables such as changes in proportions of commuter and recreational cyclists, changes in behaviour of cyclists and other road users, or improved cycling infrastructure.

		Assumed equal exposure between head and limb injuries which allowed an arbitrary proxy exposure to be used in the model. Analyses were also performed for pedestrian data to identify which of the observed effects were specific to cyclists			Complications between seasonal accident adjustment and regression modelling with negative binomials.

Author	Aim	Study design	Sample size	Results	Implications
Wesson et al (2008) **Country** Canada **Helmet legislation** Ontario (<18 years)	Examine bicycle-related mortality rates in Ontario, Canada, from 1991-2002 among children (1-15 years) and adults (>16 years), and determine the effect of MHLs on mortality rates.	Quasi-experimental (time series) **Data collection** Bicycle-related fatality data between 1991-2002, including all injury mechanisms and levels of severity (Office of the Chief Coroner of Ontario). **Analysis** Time series analysis used to determine whether the introduction of MHL was associated with significant changes in numbers of deaths. Adjusted for mortality rates (deaths per 105 years) using death counts from coroner's office and population estimates. Seasonal autocorrelation adjusted for by using	1-15 yrs: 107 deaths 16+ yrs: 255 deaths **Age (mean)** n/a **Male (%)** n/a	There were 362 bicycle-related deaths in the 12-year period (1–15 years: 107 deaths; >16 years: 255 deaths). Significant reductions in the number of deaths after October 1995 for bicyclists 1-15 years (-0.59 deaths per month). No significant change in the number of deaths for those >16 years (+0.09 deaths per month). Time series analyses demonstrated significant reductions in the numbers of deaths per month in children after October 1995, when helmet legislation was enforced in Ontario. The time series analysis did not demonstrate changes in the numbers of deaths for bicyclists 16 years of age	Reductions in the mortality rate in the younger age group was attributable, at least in part, to the introduction of the MHL. It is most likely that multiple factors, including education, promotion, and secular trends, (also) contributed to this decrease. **Limitations** The accuracy of the data collected by the Office of the Chief Coroner of Ontario is not known.

	seasonal dummy values for calendar months. Ljung-Box goodness-of-fit measure applied to final time series model	through adulthood after October 1995.	

Findings

Q1: What are the effects of helmet laws on bicycle ridership?

There is a general paucity of reliable data available that clearly establishes connections between MHLs and bicycle ridership. Indeed, Macpherson and Spinks (2008) conducted a systematic review on the effects of MHLs with respect to bicycle-related head injuries, helmet use, and bicycle use; the authors found no studies that reported variations in bicycle use as a result of MHLs, and thus could draw no conclusions on this relationship.

This shortcoming is partly due to the lack of studies with appropriate designs and sampling methods to robustly establish causal links between MHLs and bicycle ridership (Oliver et al., 2016). For example, Cameron et al. (1994; excluded) undertook observational traffic surveys in Melbourne to assess bicycle use across the period of helmet legislation (1990-1992). However, no data was collected for adult bicycle riders prior to helmet legislation taking effect, thus providing no valid control for analysis.

Two studies were found to have reasonably un-biased quantitative data on the topic. A study by Dennis et al. (2009) assessed variations in bicycle use across Canadian provinces during periods before and after the implementation of helmet legislation. The authors found that, when compared to provinces where no legislation was enforced, provinces that introduced MHLs showed no significant variation in bicycle use. This suggests that Canadian MHL implementation did not influence a deterrent effect on people riding bicycles. Olivier et al. (2016) reported on stratified random sample data from the National Cycling Participation Survey, which suggested no significant variations on cycling frequency following the implementation of MHLs in South Australia and Western Australia. However, it is unknown whether other states also experienced this lack of variation.

A further two studies explored relationships between cycle use with more novel approaches. Rissel and Wen (2011) ran computer-assisted telephone interviews with participants in Sydney to assess whether they would cycle more if the Australian MHL was repealed. While not providing primary ridership data, the study was included in this review to gather qualitative insights on people’s perspectives of MHLs in Australia. One fifth of participants said they would cycle more if they did not have to wear a helmet; and a third stated that they did not support MHLs. This may suggest that, if the Australian MHL was repealed, a portion of Sydney’s residents would resume or take up bicycle riding. However, it is worth noting that telephone interview data may be biased towards people at home and willing to give their opinion. Another study by de Jong (2012) used helmet efficacy, cycling use and health benefit data to quantitatively model the net benefit:cost ratio for cycling under an MHL. These models found that reduced cycling had negative net health benefits compared to costs. While the model reveals important relationships between cycle use, health and costs; its application to real-life settings only holds if the underlying cycle count data to construct the model is reliable. This count data was taken from Robinson (1996; 2001; 2005, excluded), which in turn was collected from a convenience sample in an organizational report (Finch et al., 1993; excluded) . Given the issues of bias in convenience sampling raised by Olivier et al. (2016), it is questionable whether the model has a firm grounding in reality.

Overall, while there is some evidence that MHLs may not affect bicycle ridership, there is simply an inefficient amount of well-grounded studies to draw a robust conclusion. This is mainly due to complications with producing non-biased data that is reasonably free of confounders. A lack of unbiased quantitative data collected at the time of helmet legislation over 30 years ago directly contributes to this issue.

Q2: What are the effects of a helmet laws on the prevalence of bicycle-related serious injuries and fatalities?

Australia

Three studies were found that examine causal relationships between the Australian MHL and severe head injuries. No reliable studies were found that focused on bicycle-related fatalities in Australia. A common method used to assess the effectiveness of MHLs in mitigating serious head injuries is by using a case-control study of hospital or trauma registry data, where variations in head injuries (sample) are compared with non-head injuries (control) across the period when MHLs have been introduced. Olivier et al. (2013) analysed changes in bicycle-related head and arm injury prevalence between 1991-2010 in New South Wales. The authors found that, while both head and arm injuries increased in frequency over the study period, head injury counts were considerably lower and increasing at a much slower rate, suggesting a beneficial effect of MHLs in reducing head injuries. (The authors also suggested that increases in limb injuries could be used as a proxy for increased ridership, however the efficacy of this measure is not validated.)

Quantitative case-control studies were also undertaken by Walter et al. (2011), who found that cycling-related head injuries declined at a higher rate than arm injuries following the period at which the state-based MHL was implemented. However, while this may suggest a net positive effect of the Australian MHL, these authors also observed declining rates of head injuries prior to the MHL being implemented. A similar observation was reported by Robinson (1996), who showed that traffic accident claims for non-head injuries in pedestrians were also declining before and after the Australian MHL was implemented. Together, these observations suggest that co-interventions, such as major road safety initiatives for speeding and drink-driving, also assisted in reducing head injuries. Walter et al. (2011), however, showed that head injury rates were decreasing significantly more than leg or arm injury rates among cyclists but not pedestrians. Based on Walter et al.'s two forms of case-control data, the authors concluded that, while broader road safety interventions may have contributed to declines in bicycle-related injury rates, the distinction between cyclist and non-cyclist head:limb injury rates suggested protective effects specifically related to the Australian MHL.

If these included studies are considered on equal merit, the effectiveness of the Australian MHL remains contentious. However, emphasis should be given to the studies of Walter et al. (2011) and Olivier et al. (2013), based on the quality of their methods. Combined, these methods include: (i) a wealth of primary data covering >10 years; (ii) adjustments for confounders (e.g. population growth, ridership variations estimated from bicycle imports); and (iii) multiple forms of case-control in their approach (e.g. head-limb, cyclist-pedestrian). The studies suggest an overall protective effect of the MHL on serious head injuries in Australia. However, this conclusion still relies on data that has been demonstrated as being affected by co-interventions.

Canada, USA, and New Zealand

Three studies have examined MHLs in Canada, each of which have found them to have no significant association with serious injury or fatality. An early study by Wesson et al. (2008) compared bicycle related-deaths involving children (1-15 years) with those involving older adolescents and adults (>16 years), before and after the implementation of Ontario's MHL for bicycle riders <18 years. The time series analysis did not demonstrate changes in the numbers of deaths for bicyclists >16 years old after the MHL was implemented. However, it is hard to separate older adolescents (16-18 years) from adults (>18 years) in the study, the latter of which are not regulated to wear helmets. Dennis et al. (2013) found no statistically significant effects of province-specific MHLs on the rates of hospital admissions for cycling-related head injuries versus all other cycling-related injuries. The authors also noted that cycling-injury rates were already decreasing prior to the implementation of MHLs across Canada, which suggests that other interventions played a role in decreasing cyclist injuries. A more recent study by Teschke et al. (2015) integrated hospital admission data with bicycle trip data from Canadian health surveys to calculate exposure-based hospitalisation rates for cyclists. The study found no significant association between Canadian MHLs and hospitalisation rates for brain, head, scalp, skull, face or neck injuries, which suggests that MHLs were not effective at preventing these injury types.

Three studies have examined MHLs in the US; and have generally concluded that they have been ineffective. Ji et al. (2006) assessed the effects of a Californian MHL (<18 years; est. 1993) on injury rates in San Diego County. The authors found that, while helmet use had a protective effect for the cycling population, there was insufficient evidence that the MHL alone reduced head injury rates. A later study by Castle et al. (2012) found that the Californian MHL did not increase rates of helmet use, nor decrease rates of head injury in Los Angeles County. Overall, the studies suggest that the Californian MHL does not adequately protect against serious injury or death in people riding bikes. A third study by Kett et al. (2016) examined bicycle-related serious injury and fatalities in Seattle and King County, provinces with enforced MHLs (Seattle est. 2003; King County est. 1994). The authors found that head trauma prevalence decreased significantly in Seattle but not in King County; however, there was an overall significant decrease in the severity of bicycle-related TBI and the number of fatalities in both provinces. The results imply that these MHLs may have contributed to bicycle-related injury prevention.

The New Zealand MHL (est. 1994) has been evaluated in two studies. Povey et al. (1999) used hospital admission and helmet use data to demonstrate that increases in the helmet wearing rate reduced the risk of head injury in cycling accidents, particularly in non-motor vehicle crashes. However, the study was later criticised by Robinson (2001), who described how a pre-existing trend may have biased their results. When helmet use and head injury data were integrated, the substantial increase in helmet wearing did not coincide with the moderate downward trend in injury rates that Povey et al. used to draw their interpretations. A later study by Scuffham et al. (2000) argued that helmet wearing rates in New Zealand were associated with decreased head injury across different age groups and head injury types (e.g. lacerations, fracture, brain injury). Odds ratio results in the study demonstrate a decrease in head injuries (sample) to cyclists was greater than the decrease in non-head injuries (control).

Possible biases

Several considerations should be made when evaluating the findings in Q2. Firstly, there is an inevitable bias in using police report data, as people will not always report minor or non-injury accidents. Police data may also include fatalities not caused by head injuries, such as abdominal or chest injuries – where a cycle helmet is not the protective measure (Hynd et al., 2011). Similarly, any potentially serious injuries that were ameliorated by helmets will be under-represented in data for trauma registries and hospitals (Ji et al., 2006; Castle et al., 2012; Hooper and Spicer, 2012). Thus, there is an inevitable bias towards higher impact accidents in these records. A further limitation of broader injury data is that it is event-based, and does not take into account the degree of cycling exposure (i.e. number of hours spent cycling). It is therefore hard to assess the likelihood of accidents, calculate incident rates, or determine the level of risk to people riding bicycles. Some authors have overcome this by using national surveys to calculate average trip data (e.g. Teschke et al., 2015).

Studies on the Australian MHL show that co-interventions may have a contributory effect in reducing bicycle-related serious head injuries (e.g. Walter et al., 2011). This effect has also been found Canada (Dennis el al., 2009), and the US (Castle et al., 2012). These studies illustrate the complications with isolating the effect of MHLs on bicycle injury time series data.

Trends in bicycle-related injury data may also be biased due to behavioural changes. Robinson (1996) argued that the persistence of injuries post-MHL (despite observations of decreased bicycle use) is attributable to ‘risk compensation’, a phenomenon whereby protected cyclists undertake riskier behaviours. While the existence of risk compensation in Australia bicycle use is beyond the scope of this review, Robinson raises valid points of consideration regarding the collection, analysis and interpretation of such injury data.

Together, these limitations convey the complex nature of measuring and assessing MHL effectiveness. Future studies should attempt to isolate whether an MHL alone is an effective preventative measure for bicycle-related accidents involving serious injury and fatality, and whether confounding variables and co-interventions (e.g. improved cycling infrastructure, driver/bicycle rider education) bias the results.

Themes

The themes identified by this rapid review relating to MHLs, bicycle ridership, and the prevalence of bicycle accidents involving serious injury/fatality are set out below:

1. **A lack of reliable data on bicycle ridership** – While a small number of studies were found examining the relationship between MHLs and bicycle ridership, the methodologies and sampling techniques are highly susceptible to bias, and therefore causal links are difficult to establish.
2. **MHLs may protect against bicycle-related serious injury in Australia** – If the most reliable data and study designs are given proper emphasis (e.g. Walter et al., 2011; Olivier et al., 2013), the literature suggests an overall protective effect of the MHL on serious head injuries in Australia.
3. **The effectiveness of MHLs outside Australia are mixed** – Studies examining MHLs in Canada and the US reveal that they are generally ineffective at preventing serious injury (e.g. Dennis et al., 2009; Kett et al., 2016) and death (e.g. Wesson et al., 2007). However, some studies suggest that the New Zealand MHL may have decreased rates of serious head injury (Scuffham et al., 2000).
4. **Published data on bicycle-related injuries often carries bias** – The reliability of bicycle-related injury data is potentially compromised by biases such as uncontrolled confounding factors (e.g. pre-existing trends; Robinson, 2001), convenience sampling, and a lack of exposure-based data. There are also several shortcomings with commonly used data such as police reports and hospital admissions.
5. **Head injury rates commonly decline prior to MHL implementation** – In conjunction with theme 4, many studies have shown that bicycle-related injury data had already been in decline prior to MHLs being implemented (Dennis el al., 2009; Walter et al., 2011; Castle et al., 2012). These observations are likely related to coexisting road traffic safety initiatives and may further bias data.
6. **MHLs alone will not protect persons riding bicycles against risks** – Most authors, either arguing for and against the effectiveness of MHLs, agree that helmets alone will not reduce the risks people are exposed to when riding bicycles. Consideration must also be given to driver-cyclist education, bicycle rider conspicuity, speed restrictions, and improved bicycle infrastructure.

Limitations

Some limitations of this rapid review require careful consideration. Firstly, no grey literature was used in the review. This includes government reports where primary data pertinent to the research questions may have been presented. This is particularly relevant to annual literature containing bicycle rider counts, such as the National Cycling Participation Survey and Bicycle Network's Super Counts program. However, as these publications do not undergo critical appraisal by external peers, there exists a risk of bias with respect to the data collection, analysis and interpretation. Given the divisive nature of the review topic and the need for reliable data with minimal bias, it was decided to not include these types of publication in the review.

A second possible limitation is that data relevant to this review (e.g. bicycle usage rates) may be a secondary outcome within studies of which the primary outcome is different (e.g. quantifying helmet usage rates). This means that relevant data may be 'hidden' within studies and may not have been captured by the search terms used in this review. This casts a limitation on the systematic nature of the review.

Conclusions

This rapid review identified literature relating to the effects of a mandatory bicycle helmet law (MHL) on (i) bicycle ridership; and (ii) the prevalence of bicycle-related accidents involving serious injury or fatality. Due to a paucity of reliable data, the link between ridership and MHLs was inconclusive. Some evidence was found for a protective effect of MHLs against accidents involving serious injuries in Australia and New Zealand, but not elsewhere. However, these study findings are potentially affected by several forms of bias. Overall, the review highlights the complexities of deriving reliable primary data for the effectiveness of MHLs and the role these laws play in cyclist safety.

It should be evident that a bicycle helmet does not increase or decrease the likelihood of an accident, but rather is a protective measure in the event of an accident. The likelihood of a bicycle-related accident, therefore, is not explicitly dependent on helmet use nor any legislation enforcing it. Mitigating serious accidents goes beyond enforcing protective wear such as helmets; it involves a process of identifying and targeting the diverse range of environmental risks that cyclists are exposed to.

Most authors agree that achieving reasonable cyclist safety is likely to be an integrative approach combining protective measures (e.g. helmets, hi-vis wear) and interventions that minimise the associated risks (e.g. increased cycling infrastructure, cycle-supportive legislation). Emphasis on the effectiveness of MHLs may detract from the broader interventions, challenges and strategies for increasing cycle safety and the uptake of people riding bicycles.

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Appendices

Appendix 1: List of included studies

Q1: What are the effects of helmet laws on bicycle ridership?

de Jong, P. (2012). The Health Impact of Mandatory Bicycle Helmet Laws. Risk Analysis, 32(5), 782-790.

Dennis, J., Potter, B., Ramsay, T., & Zarychanski, R. (2009). The effects of provincial bicycle helmet legislation on helmet use and bicycle ridership in Canada. Injury Prevention, 16(4), 219-224.

Macpherson, A., & Spinks, A. (2008). Bicycle helmet legislation for the uptake of helmet use and prevention of head injuries. Cochrane Database of Systematic Reviews (3), CD005401.

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Rissel, C., & Wen, L. M. (2011). The possible effect on frequency of cycling if mandatory bicycle helmet legislation was repealed in Sydney, Australia: a cross sectional survey. Health Promotion Journal of Australia, 22(3), 178-183.

Q2: What are the effects of a helmet laws on the prevalence of bicycle-related serious injuries and fatalities?

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Wesson, D. E., Stephens, D., Lam, K., Parsons, D., Spence, L., & Parkin, P. C. (2008). Trends in pediatric and adult bicycling deaths before and after passage of a bicycle helmet law. Pediatrics, 122(3), 605-610.

Appendix 2: List of excluded studies (full-text screening and data extraction)

Abu-Zidan, F. M., Nagelkerke, N., & Rao, S. (2007). Factors affecting severity of bicycle-related injuries: the role of helmets in preventing head injuries. Emergency Medicine Australasia, 19(4), 366-371.

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Appendix 3: Example of 'risk of bias' assessment criteria

JBI Critical Appraisal Checklist for Quasi-experimental Studies

Reviewer____Date____________________

Author ____Year________Record Number______

	Yes	No	Unclear	Not applicable
1. Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?	☐	☐	☐	☐
2. Were the participants included in any comparisons similar?	☐	☐	☐	☐
3. Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	☐	☐	☐	☐
4. Was there a control group?	☐	☐	☐	☐
5. Were there multiple measurements of the outcome both pre and post the intervention/exposure?	☐	☐	☐	☐
6. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analysed?	☐	☐	☐	☐
7. Were the outcomes of participants included in any comparisons measured in the same way?	☐	☐	☐	☐
8. Were outcomes measured in a reliable way?	☐	☐	☐	☐
9. Was appropriate statistical analysis used?	☐	☐	☐	☐

Additional study-specific items

Were injuries medically diagnosed?

Were severity scales (e.g. AIS, ISS) reported?

Were the control groups valid?

Were confounding variables (e.g. time of day) accounted for?

Overall appraisal: **Include** ☐ **Exclude** ☐ **Seek further info** ☐

Comments (Including reason for exclusion)

Appendix 4: Risk of bias assessment criteria

To ensure replicability and validity in the findings, articles included in the review underwent a risk-of-bias assessment using the Joanna Briggs critical appraisal criteria[2] defined below. Most articles were deemed satisfactory for inclusion in the review. All assessments are summarized in Appendix 5.

Quasi-experimental studies

1. Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?
2. Were the participants included in any comparisons similar?
3. Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?
4. Was there a control group?
5. Were there multiple measurements of the outcome both pre and post the intervention/exposure?
6. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?
7. Were the outcomes of participants included in any comparisons measured in the same way?
8. Were outcomes measured in a reliable way?
9. Was appropriate statistical analysis used?

Cohort studies

1. Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?
2. Were the participants included in any comparisons similar?
3. Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?
4. Was there a control group?
5. Were there multiple measurements of the outcome both pre and post the intervention/exposure?
6. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?
7. Were the outcomes of participants included in any comparisons measured in the same way?
8. Were outcomes measured in a reliable way?
9. Was appropriate statistical analysis used?

Systematic reviews

1. Is the review question clearly and explicitly stated?
2. Were the inclusion criteria appropriate for the review question?
3. Was the search strategy appropriate?
4. Were the sources and resources used to search for studies adequate?
5. Were the criteria for appraising studies appropriate?
6. Was critical appraisal conducted by two or more reviewers independently?
7. Were there methods to minimize errors in data extraction?
8. Were the methods used to combine studies appropriate?
9. Was the likelihood of publication bias assessed?
10. Were recommendations for policy and/or practice supported by the reported data?
11. Were the specific directives for new research appropriate?

[2] Joanna-Briggs Institute: http://joannabriggs.org/research/critical-appraisal-tools.html

Appendix 5: Risk of bias assessment summaries

Q1: What are the effects of helmet laws on bicycle ridership?

Quantitative studies

Author	Year	Cause' and 'effect' defined?	Similarity between participants?	Similar treatment/ care?	Control group?	Multiple measurements of outcome?	Follow up complete?	Similar outcome measures?	Reliable outcome measures?	Appropriate statistical analysis?	Include	Exclude	Notes
Cameron	1993	U	NA	NA	-	-	U	-	-	U		x	Insufficient data to establish causal link
Clarke	2006	+	NA	NA	-	-	-	U	U	+		x	Insufficient data to establish causal link
Clarke	2012	+	NA	NA	-	-	-	U	U	+		x	Insufficient data to establish causal link
Curnow	2008	+	NA	NA	-	-	-	U	U	-		x	Insufficient data to establish causal link
de Jong	2012	+	NA	NA	NA	+	NA	+	+	+	x		
Dennis	2009	+	U	U	+	+	NA	+	U	+	x		
Olivier	2016	+	NA	-	-	+	NA	+	+	+	x		
Rissel	2011	+	+	NA	-	-	+	+	+	+	x		
Robinson	2005	U	U	NA	-	-	U	NA	U	U		x	Insufficient data to establish causal link

Systematic Reviews

Author	Year	Question explicitly stated?	Inclusion criteria appropriate?	Search strategy appropriate?	Resources adequate?	Critical appraisal appropriate?	2+ independent reviewers?	Combining appropriate?	Publication bias assessed?	Policy?	Research?	Include	Exclude	Notes
Macpherson and Spinks	2008	+	+	+	+	+	+	+	+	+	+	x		

Q2: What are the effects of a helmet laws on the prevalence of bicycle-related serious injuries and fatalities?

Quantitative studies

Author	Year	Cause' and 'effect' defined?	Similarity between participants?	Similar treatment/ care?	Control group?	Multiple measurements of outcome?	Follow up complete?	Similar outcome measures?	Reliable outcome measures?	Appropriate statistical analysis?	Include	Exclude	Notes
Cameron	1993	U	NA	NA	-	-	U	-	-	U		x	
Castle	2012	+	NA	NA	NA	U	NA	+	+	+	x		
Clarke	2006	+	NA	NA	-	-	-	U	U	+		x	Insufficient data to establish causal link
Cooke	1993	+	NA	NA	-	-	NA	-	-	-		x	Insufficient data to establish causal link
Dennis	2013	+	U	-	+	+	NA	+	+	+	x		
Ji	2006	+	U	-	+	+	NA	+	+	+	x		
Kett	2016	+	+	-	+	+	NA	+	+	+	x		
McDermott	1995	-	-	-	-	+	U	-	-	+		x	Insufficient data to establish causal link
Olivier	2013	+	NA	U	+	+	NA	+	+	+	x		
Povey	1999	+	U	U	NA	+	NA	+	+	+	x		
Robinson	1996	+	U	NA	-	+	NA	+	U	+	x		
Robinson	2001	+	NA	NA	NA	NA	NA	+	+	+	x		
Scuffham	2000	+	+	NA	+	+	NA	+	+	+	x		
Teschke	2015	U	+	NA	+	+	NA	+	+	+	x		
Voukelatos	2010	+	+	NA	+	+	NA	+	+	+		x	Paper retracted
Vulcan	1992	+	NA	NA	-	-	-	U	U	+		x	Insufficient data to establish causal link
Walter	2011	+	+	NA	+	+	NA	+	+	+	x		
Wesson	2008	+	+	NA	+	+	NA	+	+	+	x		
Yilmaz	2013	+	NA	NA	+	NA	NA	+	+	+		x	Not a valid control group

Systematic Reviews

Author	Year	Question explicitly stated?	Inclusion criteria appropriate?	Search strategy appropriate?	Resources adequate?	Critical appraisal appropriate?	2+ independent reviewers?	Combining appropriate?	Publication bias assessed?	Policy?	Research?	Include	Exclude	Notes
Macpherson and Spinks	2008	+	+	+	+	+	+	+	+	+	+	**x**		