School of Mathematics and Statistics
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Bicycle Helmets: Systematic Reviews on Legislation, Effects of Legislation on Cycling Exposure, and Risk Compensation

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Executive Summary

Introduction

Cycling has been shown to have health and environmental benefits, but there are also inherent risks including serious and fatal injury. Head injuries are common among cycling hospitalisations and fatalities, and bicycle helmets have been designed to mitigate head injuries in a crash or fall. Biomechanical and epidemiological evidence suggests wearing a bicycle helmet substantially reduces the risk and odds of head and face injury of any severity, serious head injury, and fatal head injury.

Bicycle helmet legislation (BHL) has been introduced in many jurisdictions to increase helmet wearing among cyclists. Past studies indicate BHL is associated with increased helmet wearing and reductions in cycling head injury.

Critics of bicycle helmet legislation argue BHL deters people from cycling. Several sources claim the reduction due to BHL is approximately of 30-40% which is often used as a reason against the creation of new helmet laws or to repeal current ones. However, there are other studies that have found no reductions in cycling following helmet legislation.

Those critical of helmet use argue the use of protective equipment such as a helmet are counterproductive due to risk compensation. This hypothesis posits that wearing a helmet might lead cyclists to engage in riskier behaviours. There is a lack of consensus in this area with supportive and non-supportive studies in the literature, and previous calls for a systematic review on bicycle helmets and risk compensation have gone unanswered.

The objectives of this study were (1) to systematically identify and describe bicycle helmet laws worldwide, (2) to systematically review the evidence bicycle helmet legislation is associated with reductions in cycling, and (3) to systematically review the evidence wearing a bicycle helmet will increase a cyclist’s risky behaviour.

Bicycle helmet laws

Our systematic review identified twenty-eight countries with BHL including Argentina, Australia, Austria, parts of Canada, Chile, Croatia, Czech Republic, Estonia, Finland, France, Iceland, Israel, Japan, Jersey, Latvia, Lithuania, Malta, Namibia, New Zealand, Nigeria, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, United Arab Emirates and parts of the United States. These laws differ substantially with regards to maximum applicable age and level of enforcement.

Nine countries have all-ages helmet laws (Argentina, Australia, Finland, Malta, Namibia, New Zealand, Nigeria, South Africa, and United Arab Emirates) as well as half of Canadian provinces, some US cities, urban travel in Chile and Slovakia, and interurban travel in Israel and Spain. Out of 273 helmet laws worldwide, two have been fully repealed. Approximately half of the members of the Organisation for Economic Co-operation and Development (OECD), the International Traffic Safety and Data Analysis Group, and the European Union have some form of bicycle helmet legislation.

Bicycle helmet legislation and cycling exposure

Our systematic review identified 35 relevant studies, reports or data sources covering 18 jurisdictions in 7 countries. In some instances, these studies were continuations of other studies and, when combined, constitute 23 unique collections of studies. Across these studies, cycling exposure was measured by kilometres travelled, number of trips, frequency of cycling, proportion of cyclists, police-reported cycling crashes, quasi-induced exposure using other cycling injuries, census of mode of travel to work, or counts of cyclists from fixed locations.

With regards to the hypothesis cycling exposure decreases due to BHL, the results from 13 studies did not support the hypothesis, 8 studies had mixed results, and two studies supported the hypothesis. The two supportive studies were based in New Zealand and the USA, and other studies from these countries did not find a consistent reduction in cycling.

Fewer children observed cycling to school was a common theme across several studies. BHL could be interpreted as a causal factor in the reduction; however, there is substantial evidence the observed reductions are due to other factors. Western Australia data indicated the reduction was part of an existing trend prior to legislation and New South Wales (NSW) data found large increases in children being driven to school beginning in the 1970's. There were no major reductions in primary school children in Victoria and the Northern Territory, or among children in Spain. In New Zealand, campaigns were introduced to discourage young children from cycling to school around the introduction of their helmet law.

It is commonly stated that 30-40% of cyclists will stop cycling if bicycle helmet legislation is introduced and that this legislation will further deter potential cyclists in the future. When taken as a whole, the evidence discussed in this report found little to no evidence bicycle helmet legislation deters cycling by any substantial amount. Instead, the majority of the evidence suggests bicycle helmet legislation is not associated with any cycling reductions.

Bicycle helmet use and risk compensation

Our systematic review identified 22 relevant articles with data on bicycle helmet use and various forms of risky behaviour. Seventeen studies were not supportive of risk compensation for bicycle helmet wearing, three studies reported results that were both in favour and against, and two studies supported the risk compensation hypothesis. Additionally, associations for ten of the non-supportive studies were in the opposite direction of risk compensation, i.e., helmet wearers were less likely to exhibit risky behaviour than non-helmet wearers. The two studies supportive of risk compensation and bicycle helmet use were based in the UK from the same laboratory.

There were important limitations among the included studies. Most studies did not directly measure whether a participant increased risky behaviour from a baseline measurement, i.e., no measured change in behaviour. Instead, many studies were cross-sectional surveys of risky behaviour that were not always related to cycling.

Overall, this systematic review identified a general lack of evidence supportive of the risk compensation hypothesis for bicycle helmet wearing, although there is also a general lack of studies that directly assess risk compensation and helmet wearing.

Discussion

The current debate around bicycle helmet legislation and, more generally, bicycle helmet use is complex, divisive and emotive. Two major arguments are that introducing bicycle helmet legislation will reduce cycling and that wearing a helmet will increase risky behaviours thereby offsetting the safety benefit offered by the helmet. The systematic reviews detailed in this report do not support either of these arguments.

Chapter 1: Bicycle Helmets and Bicycle Helmet Legislation

The health benefits of cycling have been shown in various systematic reviews of cross-sectional, longitudinal, prospective observational, and interventional studies (Oja et al, 2011; Saunders et al, 2013). The findings of these systematic reviews found cycling is associated with an improvement in cardiorespiratory fitness, cardiovascular fitness, and cardiovascular risk factors, as well as lower rates of all-cause mortality, cancer mortality, cancer morbidity, hypertension, and Type 2 diabetes (Oja et al, 2011; Saunders et al, 2013). Although cycling has clear health benefits, it is an activity that can lead to serious injury or fatality (Persaud et al, 2012; Rizzi et al, 2013). Despite the potential negative outcomes of cycling, the literature has shown that the health benefits of bicycling outweigh its risks (De Hartog et al, 2010).

Bicycle helmet wearing has been shown to mitigate the effect of head injury in a cycling related crash or fall in biomechanical (McIntosh et al, 2013; Cripton et al, 2014), computer simulation (McNally & Rosenberg, 2013; McNally & Whitehead, 2013) and systematic reviews of epidemiological studies (Thompson et al, 1999; Attewell et al, 2001; Olivier & Creighton, 2017). In an effort to reduce head injuries and societal costs resulting from such injuries, several jurisdictions around the world have enacted bicycle helmet legislation (BHL) to increase bicycle helmet wearing.

There is support for BHL by policymakers and researchers. Legislation for children and adults has been rated by the US National Highway Traffic Safety Administration as five and four-star safety countermeasures respectively (Goodwin et al, 2015). A Cochrane systematic review found BHL to be associated with increased helmet wearing and decreased cycling head injury (Macpherson & Spinks, 2008), while a more recent meta-analysis estimated BHL was associated with declines of 20% for head injury and 35% for serious head injury (Høye, 2017). Economic analyses of BHL derived in the early 2000’s estimated the value of statistical life to be in the range of US$1.1 to US$4 million dollars (Jenkins et al, 2001).

Countries with BHL have observed a sustained increase in helmet wearing. In particular, helmet wearing for Swedish children 0-10 years of age increased from 35.2% in 2004 to 64.8% in 2005 post-legislation (Bonander et al, 2014). In New South Wales (NSW), Australia, there were drastic increases in all-age helmet wearing pre- to post-BHL (Smith & Milthorpe, 1993). Bicycle helmet wearing in New Zealand was around 5% in the mid-1980's and has hovered around 90% since their BHL became effective in January 1994 (New Zealand Ministry of Transport, 2015).

Since the introduction of helmet legislation, there have been disparate arguments for and against the effectiveness of these laws. Consistent with a Cochrane Review on the impact of bicycle helmet legislation (Macpherson & Spinks, 2008), it has been empirically argued that legislation has been effective at increasing helmet use in Australia (Smith & Milthorpe, 1993; Walter et al, 2011; Walter et al, 2013; Olivier et al, 2013), Canada (Karkhaneh et al, 2013), New Zealand (New Zealand Ministry of Transport, 2015), Sweden (Bonander et al, 2014) and the United States (Kett et al, 2016).

Critics of mandatory helmet legislation, however, argue declines in ridership due to the inconvenience caused by such legislation (Robinson, 1996, 2006, 2007) and increased risky behaviour due to wearing a helmet (Adams & Hillman, 2001). These arguments have not been supported by other research which found BHL is not associated with declines in cycling (Marshall & White, 1994; Macpherson et al, 2001; Dennis et al, 2010; Haworth et al, 2010; Olivier et al, 2016; Huybers et al, 2017) and helmet use is not associated with riskier behaviour (Lardelli-Claret et al, 2003; Bambach et al, 2013; Olivier & Walter, 2013; Sethi et al, 2016).

Decline in ridership

Early research on bicycle helmet legislation originated in Australia, the first country with widespread adoption of BHL. The state of Victoria was the first jurisdiction in the world with BHL for bicycle riders with effect from July 1990. The remaining Australian states and territories followed with similar legislation by July 1992. The state governments of New South Wales, Queensland, South Australia, Victoria and Western Australia commissioned reports on changes in helmet wearing following BHL. Robinson (1996) used the counts of cyclists from the New South Wales and Victorian helmet use reports to conclude cycling ridership declined by 30-40% following legislation. This research is often cited as a reason to not mandate helmet use or to repeal current laws (see, for example, SWOV, 2012; Rojas-Rueda et al, 2013; Clarke, 2012). Similar arguments have been made to repeal the Swedish law (Sandblom, 2015).

There is a substantial body of research that has found BHL is not associated with declines in cycling. For example, Macpherson et al (2001) and Dennis et al (2010) did not find cycling declines in Canada while more recent Australian studies have drawn similar conclusions (Haworth et al, 2010; Olivier et al, 2016). Although there are studies supportive and unsupportive that BHL deters cycling, cost-benefit analyses of BHL routinely assume legislation leads to a decline in cycling (de Jong, 2012; Sieg, 2016).

To our knowledge, there have been no reviews detailing bicycle helmet legislation across all jurisdictions and there have been no systematic reviews of the effect of bicycle helmet legislation that include searches through the peer-reviewed and grey literature. Additionally, the research literature has focused almost solely on Australia, Canada, New Zealand and the US, although many other countries have some form of BHL.

Risk compensation

The use of bicycle helmets has been criticised for having a counterproductive effect due to risk compensation. This hypothesis posits that wearing a bicycle helmet might lead cyclists to engage in riskier behaviours (e.g., higher speed, disobeying traffic rules, drink alcohol and ride, etc.) due to an increased feeling of safety caused by wearing a helmet (Adams & Hillman, 2001).

Empirical research on risk compensation has shown that wearing a helmet is associated with higher speed (Phillips, Fyhri & Sagberg, 2011; Fyhri, Bjørnskau & Backer-Grøndahl, 2012; Messiah et al, 2012). It has been also argued that motorists overtake at significantly closer distances when the cyclist is wearing a helmet than not (Walker, 2007). A re-analysis of this study (Olivier & Walter, 2013), however, found the statistical significance from the original study was due to an overpowered study design and the effect vanished when passing distance was categorised by the one-metre rule. Other studies unsupportive of the risk compensation hypothesis have found helmet users were less likely to drink alcohol and cycle or to disobey traffic controls (Bambach et al, 2013; Sethi et al, 2016), while non-helmet users were more likely to engage in illegal cycling behaviour (Lardelli-Claret et al, 2003).

There is a lack of consensus in the research literature regarding bicycle helmet use and the risk compensation hypothesis. Calls to fill this knowledge gap in cycling safety date back to at least 17 years ago (Thompson, Thompson & Rivara, 2001).

Objectives

The objectives of this report are:

1. To systematically identify and summarise bicycle helmet laws that have been enacted worldwide;

2. To systematically review the effect of BHL on cycling exposure; and,

3. To systematically review the effect of bicycle helmet use on engaging in riskier behaviour.

Chapter 2: A Review of Bicycle Helmet Laws Enacted Worldwide

2.1. Introduction

There is no current, comprehensive list of bicycle helmet laws that exist around the world. Bicycle helmet legislation is an often-debated topic and these discussions should be informed by factual information. According to the Bicycle Helmet Safety Institute (2017), it has been more than three decades since the introduction of the first bicycle helmet law (BHL) in the world. The U.S. state of California was the first place to introduce bicycle helmet legislation for passengers under 5 years of age in 1987, followed by the states of New York and Massachusetts in 1989 and 1990 respectively (Bicycle Helmet Safety Institute, 2017). In July 1990, the Australian state of Victoria became the first jurisdiction to introduce BHL for riders of all ages (Carr et al, 1995). The remaining Australian states and territories introduced similar legislation by 1992 (Australian Transport Safety Bureau, 2006).

Opponents of BHL often claim that only two countries (Australia and New Zealand) have bicycle helmet legislation (Rissel & Wen, 2011; Turner, 2012; Guy, 2015; Greaves, 2016), which is then used to argue for the repeal of such legislation in Australia and to argue against the introduction of BHL in other countries. This is despite numerous research articles that have assessed the impact of BHL in other countries (Karkhaneh et al, 2013; Dennis et al, 2013; Bonander et al, 2014; Kett et al, 2016; Bauer et al, 2016). Although it is clear multiple jurisdictions have introduced BHL and despite the ongoing arguments for and against the effectiveness of BHL, there has been no systematic review to identify or summarise these laws. A summary of all bicycle helmet laws will greatly improve identifying relevant data which in turn will improve our knowledge of the potential effects of BHL.

This chapter aims to summarise bicycle helmet laws enacted worldwide. The data collected includes date of legislation, the maximum age the law applies, whether the law is enforced via fines or not, and whether the law was later modified or repealed.

2.2. Methods

A Google desktop search was conducted in January 2017 to identify jurisdictions with BHL. Several sources were identified including reports from the European Commission (2015, 2016), the Bicycle Helmet Safety Institute (2017), the International Transport Forum (2017), government websites, journal articles, technical reports, dissertations, and news articles.

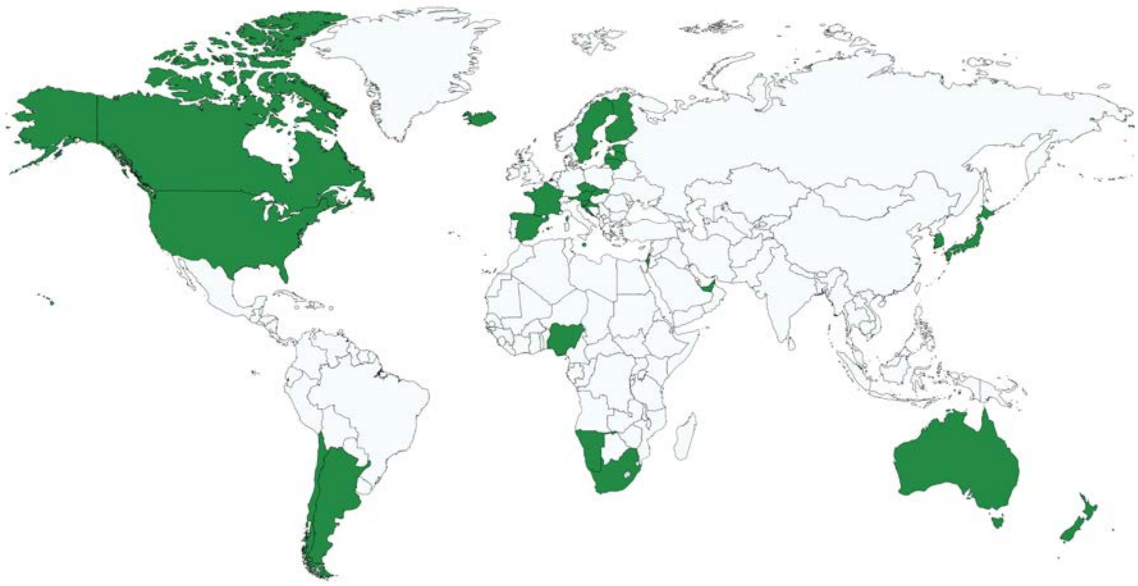
Information regarding BHL effective date, age of enforcement, and fines, were gathered using the aforementioned sources, searching government websites, and contacting road safety organisations in countries with existing BHL. Wikipedia and websites sponsored by advocacy groups such as the Bicycle Helmet Research Foundation were also searched for relevant data; however, information was included only when verified by another source. Non-English sources were translated to English using Google Translate.

2.3. Results

Our search identified 28 countries around the world with some form of bicycle helmet legislation (see Figure 2.1). This includes legislation adopted in Argentina, Australia, Austria, parts of Canada, Chile, Croatia, Czech Republic, Estonia, Finland, France, Iceland, Israel, Japan, Jersey, Latvia, Lithuania, Malta, Namibia, New Zealand, Nigeria, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, United Arab Emirates and parts of the United States. These laws differ in terms of enforcement and many apply only to children below a certain age. Nine countries have bicycle helmet laws that apply to all ages (Argentina, Australia, Finland, Malta, Namibia, New Zealand, Nigeria, South Africa, and United Arab Emirates). Additionally, five out of ten Canadian provinces and some US cities have all-ages BHL, while all cyclists must wear helmets while travelling in urban areas in Chile and Slovakia, and between urban areas in Israel and Spain.

In Australia, Canada and the United States, road rules are often created at state, provincial, territorial or city levels. Therefore, these countries are discussed separately.

Figure 2.1. Map of jurisdictions with bicycle helmet legislation



* Canada and the United States do not have legislation for all provinces or states

2.3.1. Australia

The state of Victoria was the first jurisdiction in the world to introduce bicycle helmet legislation for bicycle riders with effect from July 1990 for all ages and in all areas (Cameron et al, 1994). The remaining Australian states and territories followed with similar legislation by July 1992 (see Table 2.1).

New South Wales enacted a law for adults (16+ years of age, 1 January 1991) which was modified six months later (1 July 1991) to apply to all ages (Smith & Milthorpe, 1993). The Northern Territory (NT) first introduced legislation for adults (17+ years of age) on January 1992 and all ages by July 1992 (van Zyl, 1993). The NT law was further modified from 31 March 1994 to no longer apply to cyclists over the age of 17 who ride along footpaths or on cycle paths. Bicycle helmet legislation in the states of Queensland (July 1991) and Western Australia (January 1992) was initially introduced without enforcement, then with enforcement from January 1993 for Queensland and in July 1992 for Western Australia (King & Fraine, 1995; Healy & Maisey, 1992).

Note that although fines were not issued for the first six months in Western Australia, the police issued over 3,000 cautions during this time (Healy & Maisey, 1992), and fines of $25 could be withdrawn during the first six months of enforcement if the cyclist provided proof of a helmet purchase within 14 days of being fined.

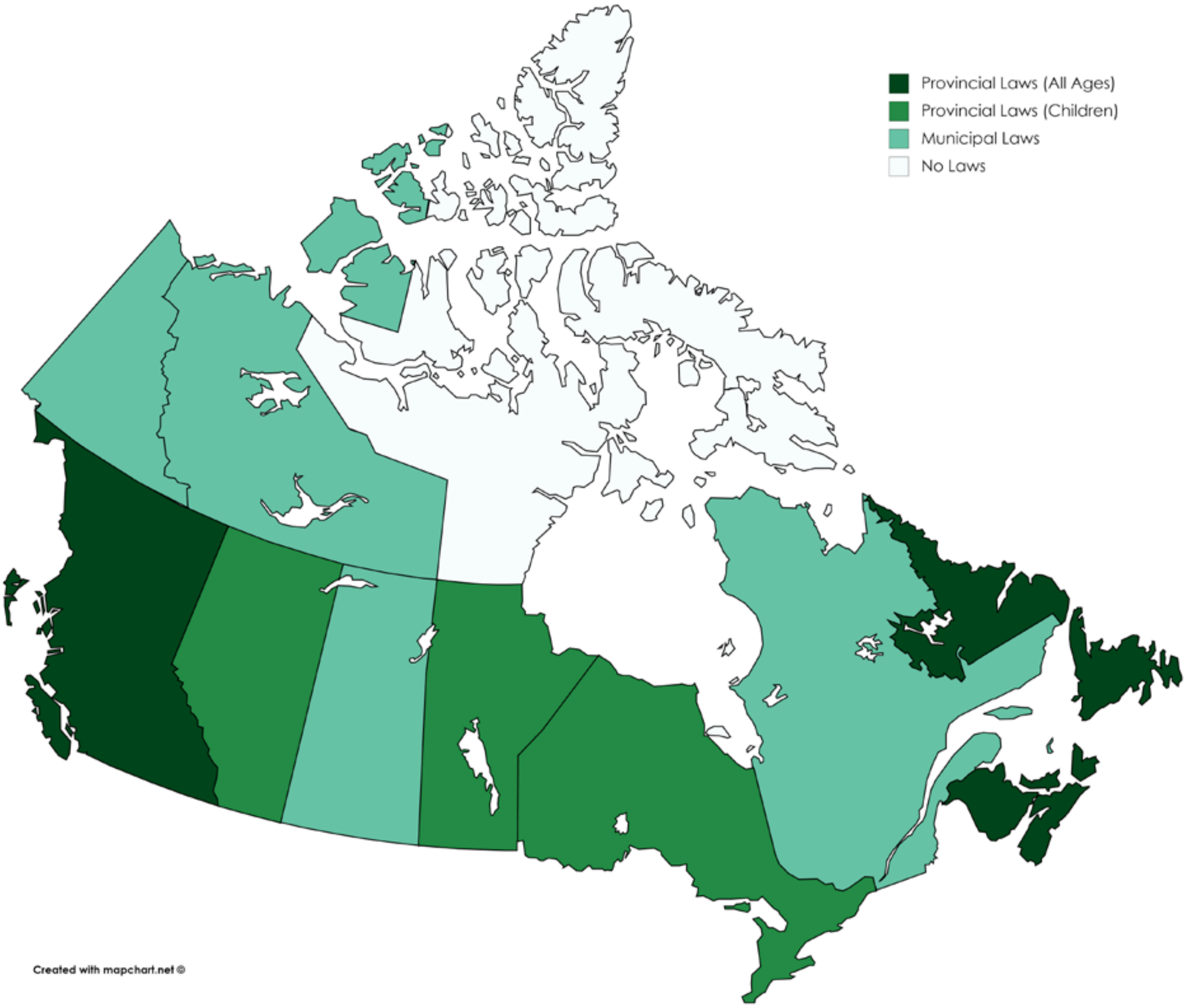
Table 2.1. Bicycle Helmet Legislation, Australia

	Effective date	Current fine (AUD)	Maximum age
Australian Capital Territory	Jul 1992	$118	All
New South Wales	Jan 1991/Jul 1991	$330	All
Northern Territory	Jan 1992/Jul 1992/Mar 1994	$25	All
Queensland	Jul 1991	$121	All
South Australia	Jul 1991	$153	All
Tasmania	Jan 1991	$260	All
Victoria	Jul 1990	$194	All
Western Australia	Jan 1992	$50	All

2.3.2. Canada

Eight out of ten Canadian provinces have some form of bicycle helmet legislation (Dennis et al, 2010; Bicycle Helmet Safety Institute, 2017). Ontario was the first province to enact BHL in October 1995, followed by seven other provinces by 2015 (see Table 2.2). The all-ages helmet law in Newfoundland and Labrador is applied to all cyclists riding on the province's roadways. A provincial map of Canadian helmet laws is given in Figure 2.2.

Figure 2.2. Map of Canadian Provinces with Bicycle Helmet Legislation



Quebec and Saskatchewan do not have bicycle helmet legislation although Yorkton, Saskatchewan has its own bicycle helmet bylaw and there are some municipal bylaws in Québec. None of the three territories of Canada (Northwest Territories (NWT), Nunavut and Yukon) has a bicycle helmet law. However, the town of Inuvik, NWT, and the city of Whitehorse, Yukon, have enacted all-ages helmet bylaws.

Canada's current population is around 37 million with Quebec at 8.4 million (23%), Saskatchewan at 1.2 million (3%) and the three territories of NWT, Nunavut and Yukon totalling around 0.12 million (0.3%) (Statistics Canada, 2018). This means that around 73.7% (27.2 million) of Canada's population is subject to some form of BHL where 20% (7.2 million) is an all ages BHL. For provinces with child only laws (Alberta, British Columbia, and

Manitoba), the population 14 years and younger was an estimated 3.2 million on 1 July 2017 (Statistics Canada, 2017).

Table 2.2. Bicycle Helmet Legislation, Canada

	Effective date	Current fine		Maximum age
		(CAD)	(AUD)[c]	
Alberta	May 2002	$69	$70	17
British Columbia	Sep 1996	$100	$102	All
Manitoba	May 2013	Up to $50[a]	Up to $51	17
New Brunswick	Dec 1995	$21	$21	All
Newfoundland & Labrador	Apr 2015	$25-$180	$26-$184	All
Nova Scotia[b]	Jul 1997	$128	$131	All
Ontario	Oct 1995	$60	$61	17
Prince Edward Island	Jul 2003	$100	$102	All

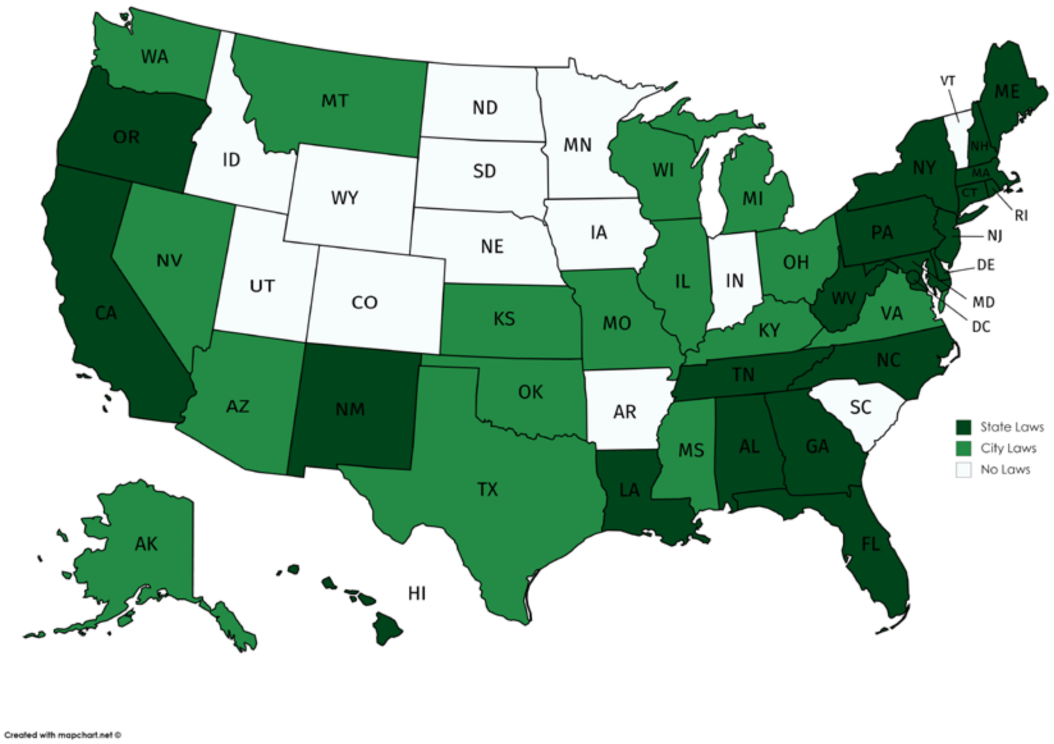
[a] Fine can be dismissed if the cyclist takes the Manitoba Bike Helmet Safety Course.
[b] Fine is replaced with a 2-hour education program delivered by police, health professionals and injury survivors
[c] Conversion rate based on 10th April 2018 exchange rate rounded to nearest dollar value

2.3.3. United States

The state of California was the first jurisdiction in the world to introduce bicycle helmet legislation, although it applied only to passengers under 5 years of age. By 2007, an additional 36 states and the District of Columbia (DC) had enacted some form of bicycle helmet legislation (see Table 2.3). Sixteen states have only city-wide laws and 13 other states do not follow any form of bicycle helmet legislation including Arkansas, Colorado, Idaho, Indiana, Iowa, Minnesota, Nebraska, North Dakota, South Carolina, South Dakota, Utah, Vermont, and Wyoming. In total, 21 states, the District of Columbia, and 203 cities, have some form of bicycle helmet legislation. Note that all state-level United States helmet laws in the US relate to children.

Further information related to the laws for each state/city of the United States can be found on the Bicycle Helmet Safety Institute website (http://www.bhsi.org/). A state map of US helmet laws is given in Figure 2.3, and Figure 2.4 summarises the US population under 18 years of age by states categorised as having state-wide helmet laws, city only laws, or no laws.

Figure 2.3. Map of US States with Bicycle Helmet Legislation



In 1994, Tennessee passed a law requiring the use of helmets for cyclists under the age of 16. There was a move to repeal the law, but it was reconfirmed in 2000. Following a referendum in the City of Seymour, Connecticut, the all-ages helmet law was repealed in September 1998, two months after its introduction in July 1998. However, helmet legislation still applies to children up to 16 years of age due to a state-wide law in Connecticut. In Dallas, Texas, all-ages bicycle helmet legislation was enacted in 1996 and was relaxed in 2014, which then applied to children under 18 years. In Snohomish, Washington, an all-ages law was repealed in 2002; however, an existing law still applies to skate parks.

The original 1987 California helmet law was later modified in 1994 to apply to child riders under 18 years of age. Similarly, the Massachusetts' 1990 law was modified in 1994 and 2004, which applied to children under 12 and 17, respectively. Bicycle helmet legislation was also modified in the state of New York. The 1989 law was modified in 1994 to apply to children under 14 years. Pennsylvania introduced legislation in 1991 for children under 5 years, which was modified in 1995 to apply to children under 12 years. Rhode Island also modified the applicable age in their 1996 law for children under 9 years to children under 16 years in 1998.

Figure 2.4. US population under 18 years of age by helmet law categories (source: US Census Bureau, 2017)

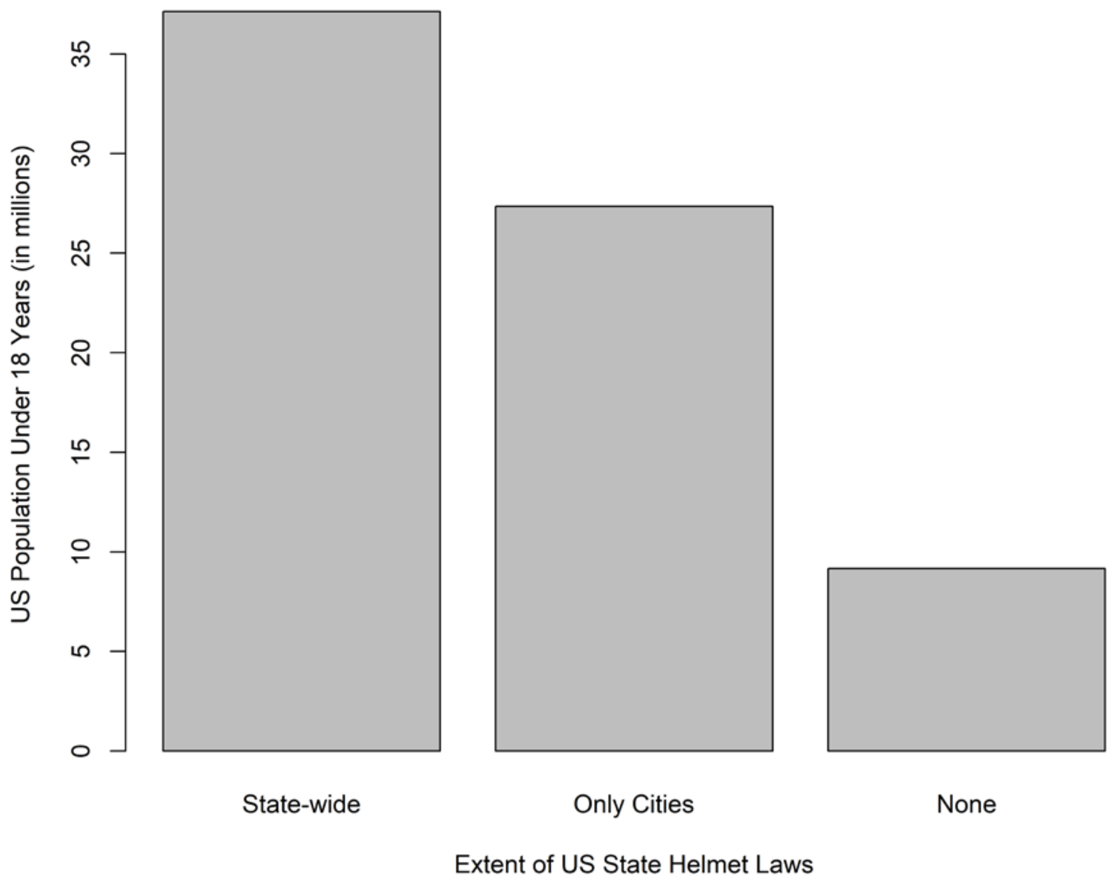


Table 2.3. Bicycle Helmet Legislation, the United States

	State or city law[a]	Effective date	Current fine		Maximum age
			(USD)	(AUD)[e]	
Alabama	S	1995	$50	$65	15
Alaska	C (5)	-	-	-	-
Arizona	C (5)	-	-	-	-
California	S	1987/1994	up to $25	Up to $32	4/17
Connecticut	S	1993/1997	No fine	No fine	15
Delaware	S	1996	$25-$50[b]	$32-$65[b]	17
District of Columbia	S	2000	$25	$32	15
Florida	S	1997	$17	$22	15
Georgia	S	1993	No fine	No fine	15
Hawaii	S	2001	$25	$32	15
Illinois	C (6)	-	-	-	-
Kansas	C (1)	-	-	-	-
Kentucky	C (1)	-	-	-	-
Louisiana	S	2002	No fine	No fine	11
Maine	S	1999	$25	$32	15
Maryland	S	1995	No fine	No fine	15
Massachusetts	S	1990/1994/2004	No fine	No fine	4/11/16
Michigan	C (3)	-	-	-	-
Mississippi	C (4)	-	-	-	-
Missouri	C (39)	-	-	-	-
Montana	C (1)	-	-	-	-
Nevada	C (2)	-	-	-	-
New Hampshire	S	2006	No fine	No fine	15
New Jersey	S	1992	up to $100	up to $129	16
New Mexico	S	2007	up to $10[c]	Up to $13[c]	17
New York	S	1989/1994	$50	$65	4/13
North Carolina	S	2001	$10[c]	$13[c]	17
Ohio	C (24)	-	-	-	-
Oklahoma	C (2)	-	-	-	-
Oregon	S	1994	$25[c]	$32[c]	15
Pennsylvania	S	1991/1995	up to $25[c]	up to $32[c]	4/11
Rhode Island	S	1996/1998	No fine	No fine	8/15
Tennessee	S	1994/2000	$2	$3	15
Texas	C (9)	-	-	-	-
Virginia	C (31)	-	-	-	-
Washington	C (34)	-	-	-	-
West Virginia	S	1996	$10[d]	$13[d]	14
Wisconsin	C (1)	-	-	-	-

[a] S = state law. C = no state law, but there is/are city law/s. Number of cities with some form of legislation in parentheses.
[b] Cyclists will be fined $25 for the first offense and $50 for each subsequent offense. [c] In New Mexico, North Carolina, Oregon, and Pennsylvania, fines for not wearing a helmet waived if the cyclist provides a proof of helmet purchase. [d] Parents will be fined $10 or be required to perform two hours in community service related to a child injury prevention program. [e] Conversion rate based on 10th April 2018 exchange rate rounded to nearest dollar value

2.3.4. Other jurisdictions

Apart from Australia, Canada, and United States, there are 25 countries with some form of bicycle helmet legislation (see Table 2.4). Among these countries, New Zealand (Povey et al, 1999) and France (Ministry of the Interior, 2016) were the first and the last to introduce legislation in 1994 and 2017, respectively.

Mexico City repealed their bicycle helmet law in February 2010, two years after its introduction in 2008. The repeal was motivated to support their shared bicycle rental program (Bicycle Helmet Safety Institute, 2017), although no evaluation of the repeal on cycling distances/trips travelled or any other measure of cycling exposure, cycling injury, or road deaths could be found. Bosnia and Herzegovina introduced an all-ages bicycle helmet law in 2006 and was later repealed in March 2017. The repeal occurred after a six-year effort by the Centre for Environment campaign (Reid, 2017). There was an initial proposal in Finland to modify or repeal their helmet law; however, any potential changes in helmet legislation have been removed from discussions of their road traffic laws (Finnish Government, 2017 (b)). Malta is currently considering repealing their bicycle helmet law; however, new rules are currently being drafted and have not taken effect (Reljic, 2018).

In Argentina, children under 12 years of age are allowed to ride in parks without having to wear helmets. In Chile, helmet wearing is mandatory in urban areas for all ages, and not obligatory when riding in rural zones. Israel modified its all-ages law enacted in 2007. Since 2011, children under 18 years and all cyclists on interurban roads must wear a helmet when cycling. Czech Republic first introduced BHL for children under 16 years in 2001 which then changed in 2006 and applied to children under 18 years. In Slovakia, cyclists of all ages must wear a helmet except for cyclists older than 15 years when riding outside populated areas. Spain modified its all-ages law in 2014 where children under 16 years must wear a helmet regardless of the route and adults must wear a helmet when riding on interurban routes, except when travelling uphill, presumably because of heat effects and travelling uphill is slower.

Table 2.4. Mandatory Helmet Legislation, All jurisdictions

	Effective date	Current fine[a]	Maximum age
Argentina	2004	No fine	All
Australia	July 1990-July 1992	A$25 – A$330	All
Austria	Jun 2011	*	12
Canada	Oct 1995-Apr 2015	C$21 - C$180 (A$21 - A$184)	All/17
Chile	2009	UTM 0.5 - 1 (A$29 - A$58)	All
Czech Republic	2001/2006	Fines apply	15/18
Croatia	2008	HRK 300 (A$64)	16
Estonia	Jul 2011	€15-20 (A$24-A$32)	16
Finland	Jan 2003	No fine	All
France	Mar 2017	€135 (A$215)	12
Iceland	Sep 1999	No fine	15
Israel	Jul 2007/Aug 2011	No fine	All/18
Japan	2008	No fine	13
Jersey	Oct 2014	Fines apply (unknown)	12
Latvia	Oct 2014	*	12
Lithuania	*	*	18
Malta	Apr 2004	*	All
Namibia	*	NAD 100 (A$11)	All
New Zealand	Jan 1994	NZD 55 (A$52)	All
Nigeria	At least since 2012	N2000 (A$7)	All
Slovakia	*	Fines apply	All
Slovenia	2000	€120 (A$191)	15
South Africa	Oct 2004	No fine	All
South Korea	2006	*	13
Spain	2004/2014	€200 (A$319)	All/15
Sweden	Jan 2005	€55[b] (A$88)	15
United Arab Emirates	2010	AED 500 (A$176)	All
United States	1987-2007	US$0 - US$100 (A$0 - A$129)	

[a] Conversion rate based on 10th April 2018 exchange rate rounded to nearest dollar value
[b] There is no penalty for children. However, parents cycling with unhelmeted children are liable to a fine of €55 Euro.
* Information was not found
ALL is law applies to 'All Ages'

There have been seventeen jurisdictions that have modified existing bicycle helmet laws, including three countries (Czech Republic, Israel, Spain), two Australian states (New South Wales, Northern Territory), six US states (California, Connecticut, Massachusetts, New York, Pennsylvania, Rhode Island), and six US cities (Austin TX, Seymour CT, Dallas TX, Snohomish WA, Southlake TX, St Louis County MO).

As summarised in the tables, the fines levied for violation of bicycle helmet legislation vary substantially among the jurisdictions. In all states of Australia, fines range from AUD25 to AUD330. In Canada, fines between CAD21 and CAD180 apply in all provinces with legislation. In the United States, fines apply in some states (between USD2 and USD100), but not all. In addition, fines apply in 12 out of the 23 other countries with some form of bicycle helmet legislation, with the highest rate in Spain (€200 which is equal to about AUD307). The Australian state of New South Wales currently has the largest fine in the world (AUD330).

2.4. Discussion

Since the introduction of the first bicycle helmet law in 1987, there have been at least 273 bicycle helmet laws enacted all over the world (encompassing countries, states, provinces, territories, and cities). Two of these laws have been fully repealed including Mexico City (2010) and Bosnia and Herzegovina (2017). To the best of our knowledge, there have been no assessments regarding the impact of these repealed laws on either cycling distances/trips travelled, injury or road deaths.

The motivation for introducing BHL is to increase bicycle helmet wearing and, consequently, decrease bicycle related head injury and fatalities as well as any associated societal costs. Although it has often been presented as being limited to Australia and New Zealand, BHL exists in many parts of the world with varying rules, enforcement levels, and affected ages.

BHL has been enacted in about half of the OECD, IRTAD and EU countries around the world irrespective of the measure. This includes nineteen of thirty-five members of the Organisation for Economic Co-operation and Development (OECD, 2018), nineteen of the forty members of the International Traffic Safety Data and Analysis Group (IRTAD)

(International Transport Forum, 2018), and thirteen of the twenty-eight members of the European Union (EU).

Bicycle helmet laws often differ across jurisdictions due to discussions and debates prior to and following enactment. The Northern Territory, for example, discussed three options based on the cyclist's age – (1) all ages, (2) young people first and then adults, and (3) adults first and then young people (van Zyl, 1993). The NT government decided on the third option since adults comprised more than 70% of cycling injuries. Other jurisdictions have pushed for helmet legislation for children only since there is greater acceptance for younger age groups than adults (Hooper & Spicer, 2012; Biegler & Johnson, 2015; Swedish Government, 2004). In Finland, there have been discussions regarding the word *yleensä* mentioned in their helmet law. This word can be translated as both "usually" or "in general", which limits the government's ability to enforce the law and has led some to interpret the law as a recommendation. Helmet laws have previously been discussed for New York City which was opposed by then mayor Michael Bloomberg. There was speculation that Bloomberg was not opposed to the law itself but to the city councilman who proposed the bill (Bateman-House, 2014).

Helmet legislation has been introduced for electric bicycles (ebikes) as well. To our knowledge, this includes all of Australia, parts of Canada, New Zealand, Switzerland, and parts of the United States. The proportion of ebikes has been rising, especially among older cyclists (Fishman & Cherry, 2016).

2.5. Limitations

There are several limitations to the current systematic review. First, jurisdictions often report laws only in their own language and an accurate translation to English may be difficult. Second, we identified conflicting information for some jurisdictions, such as Argentina, which was not listed as having a bicycle helmet law by IRTAD (ITF, 2017). However, article 40 of their road rules (Ley de transito, articulo 40) and an Argentinian legal advice website

(Luchemos por la vida, 2009) state cyclists are required to wear a protective helmet when riding a bicycle. Similarly, some sources reported that Nigeria does not have BHL; however, Nigeria has been listed with all ages BHL by IRTAD (ITF, 2017) which was verified by their road rules (regulation 195 of the National Road Traffic Regulations).

2.6. Conclusions

It is often claimed Australia and New Zealand are the only countries with bicycle helmet legislation and this claim is sometimes qualified as they are the only countries with all-ages laws. In this search, 28 countries were identified in total that have bicycle helmet legislation with nine countries (Argentina, Australia, Finland, Malta, Namibia, New Zealand, Nigeria, Slovakia, South Africa, and United Arab Emirates) having all-ages BHL. All-ages helmet laws also exist in Canada, Chile, Israel, Slovakia, Spain and the US depending on location or whether the cyclist is travelling in an urban or interurban area.

When the data is broken down in terms of countries, states, provinces, territories, and cities, there have been at least 273 bicycle helmet laws enacted worldwide. Additionally, these laws have been reasonably robust over the past 30 years with only two jurisdictions having fully repealed their laws.

Chapter 3: A Systematic Review on The Impact of Bicycle Helmet Legislation on Cycling Exposure

3.1. Introduction

The effectiveness of bicycle helmet legislation has been the subject of intense debate over the last few decades. Bicycle helmet legislation has been shown to increase helmet wearing (Smith & Milthorpe, 2012; Walter et al, 2011; Karkhaneh et al, 2013; Walter et al, 2013; Olivier et al, 2013; Bonander et al, 2014; New Zealand Ministry of Transport, 2015; Kett et al, 2016), which itself mitigates the effect of head injury in a cycling related crash or fall (Thompson et al, 1999; Attewell et al, 2001; McIntosh et al, 2013; Cripton et al, 2014; Olivier & Creighton, 2017).

Despite the encouraging role of BHL in helmet wearing and subsequently the preventing role of bicycle helmet use on the effects of head injury, opponents of BHL have argued that the disadvantages of such laws outweigh their benefits. Specifically, opponents of BHL argue that the enforcement of such laws discourages cycling which itself has a negative impact on health (Robinson, 1996, 2006, 2007). The potential impact of BHL on ridership has been used to argue for the repeal of such laws in countries with BHL, although there is not uniform support for this hypothesis in the scientific literature (Marshall & White, 1994; Macpherson et al, 2001; Dennis et al, 2010., Haworth et al, 2010; Olivier et al, 2016; Huybers et al, 2017).

Cycling exposure can be measured in several ways. For example, cycling can be measured by estimating the proportion or number of cyclists in the population or by estimating the frequency of cycling, the distance or time of trips, or the number of trips. Neither of these measures can be considered the “gold standard” as each offer unique insights into cycling within a population.

The proportion of travellers to work using a bicycle, often called bicycle mode share, can also be considered a measure of cycling exposure. However, caution should be exercised when interpreting changes in mode share since the number of cyclists and the overall number of travellers varies over time. For example, when assuming an increasing population, no change in cycling mode share implies more people cycling but this increase is proportional to increases in other transport modes. A decline in mode share, therefore, could imply no decline in cycling but instead cycling mode share has not kept up with increases in other travel modes.

Routinely collected injury data can also be used to measure exposure. Injuries are selected for which a treatment (e.g., helmet use) would not have an impact. These “other injuries” should be carefully identified to minimise bias (Marshall, 2008) and, with regards to bicycle helmets, should not include injuries for which wearing a helmet may influence the likelihood of an injury (Olivier et al, 2016). This approach is sometimes referred to as quasi-induced exposure (Stamatiadis & Deacon, 1997) or non-equivalent no-treatment controls (Walter et al, 2013). In past research on bicycle helmets, several studies have utilised versions of this approach (Povey et al, 1999; Walter et al, 2011; Bonander et al, 2014).

Previous research has used direct observations of cyclists at fixed locations as a measure of cycling exposure (Van Zyl, 1993; Cameron et al, 1994; Macpherson et al, 2001; Macpherson et al, 2006; Karkhaneh, 2011; Huybers et al, 2017). However, it is not possible to guarantee the observed cyclists from these study designs are representative of the general cycling population and these counts cannot be used to estimate other measures of cycling exposure. A notable exception is when children are observed cycling into or from a school since a school is a closed population, although generalisations to unobserved schools may be specious.

There are benefits to measuring cycling exposure through self-reported surveys. The sample can be identified through various forms of random sampling which helps minimise selection bias. Multiple questions can be asked to estimate multiple forms of cycling exposure. The Netherlands, for example, use this method to provide yearly estimates of distances travelled by various transport modes which can be further stratified by gender and age group (SWOV, 2013). Although there are clear strengths to these study designs, recall bias is a concern considering participants may not accurately remember past events. The use of diaries, where participants record their daily travel, can minimise the influence of recall bias.

In this study, we aim to systematically review and summarise the peer-reviewed and grey literature on the effects of BHL on ridership to examine whether cyclists have been deterred after the introduction of BHL.

3.2. Methods

Both the peer-reviewed literature and the grey literature were searched to identify relevant cycling data in jurisdictions with BHL. For the peer-reviewed literature, five electronic databases (EMBASE, MEDLINE, COMPENDEX, SCOPUS, and WEB OF SIENCE) were searched. The electronic search was independently performed by two study authors on 16 February 2017. Broad search terms were used (helmet* AND (bicycl* OR cycl*)) to minimise the possibility of missing relevant articles. For EMBASE and MEDLINE searches, the subject headings for “helmet” and “bicycling” were used. Google Scholar alerts were used to identify relevant articles published after the original search date.

Full text, English and non-English language articles were included if they reported first instance data in relation to the association between bicycle helmet legislation and cycling. Commentaries, responses to letters, as well as articles with no first instance data were included for a full-text review; however, any relevant data were extracted from the source material. When the same data were presented in two or more studies, all studies were included with the more comprehensive or most recent study taking precedence. In the absence of relevant data in a study that met other inclusion criteria, study authors were contacted. Similarly, when only an abstract that met other criteria was published, a search for a full-length article was conducted and study authors were contacted. Two study authors independently assessed the articles against inclusion criteria and data extracted with adherence to the PRISMA statement (Moher et al, 2009). Finally, disagreements between the two reviewers were discussed until a consensus was reached or adjudicated by a third author.

The grey literature was identified by searching government websites, contacting road safety organisations in countries with existing BHL, and searching websites sponsored by helmet advocacy organisations such as the Bicycle Helmet Research Foundation for relevant data. Information extracted from advocacy websites were used only if they were verified by other sources. Non-English sources were translated to English using Google Translate. Finally, studies that met the inclusion criteria were read in full by two study authors and relevant data were extracted.

As discussed in the introduction, there are inherent weaknesses in measuring cycling exposure. Direct observation of cyclists at fixed locations is the weakest study design to measure cycling exposure due to a non-representative sample and inability to generalise observations to the cycling population. For these reasons, it may be argued studies using this design should be excluded from this review. In the spirit of transparency and to present all available data relevant to this debate, the authors of this report have decided not to exclude studies using this design.

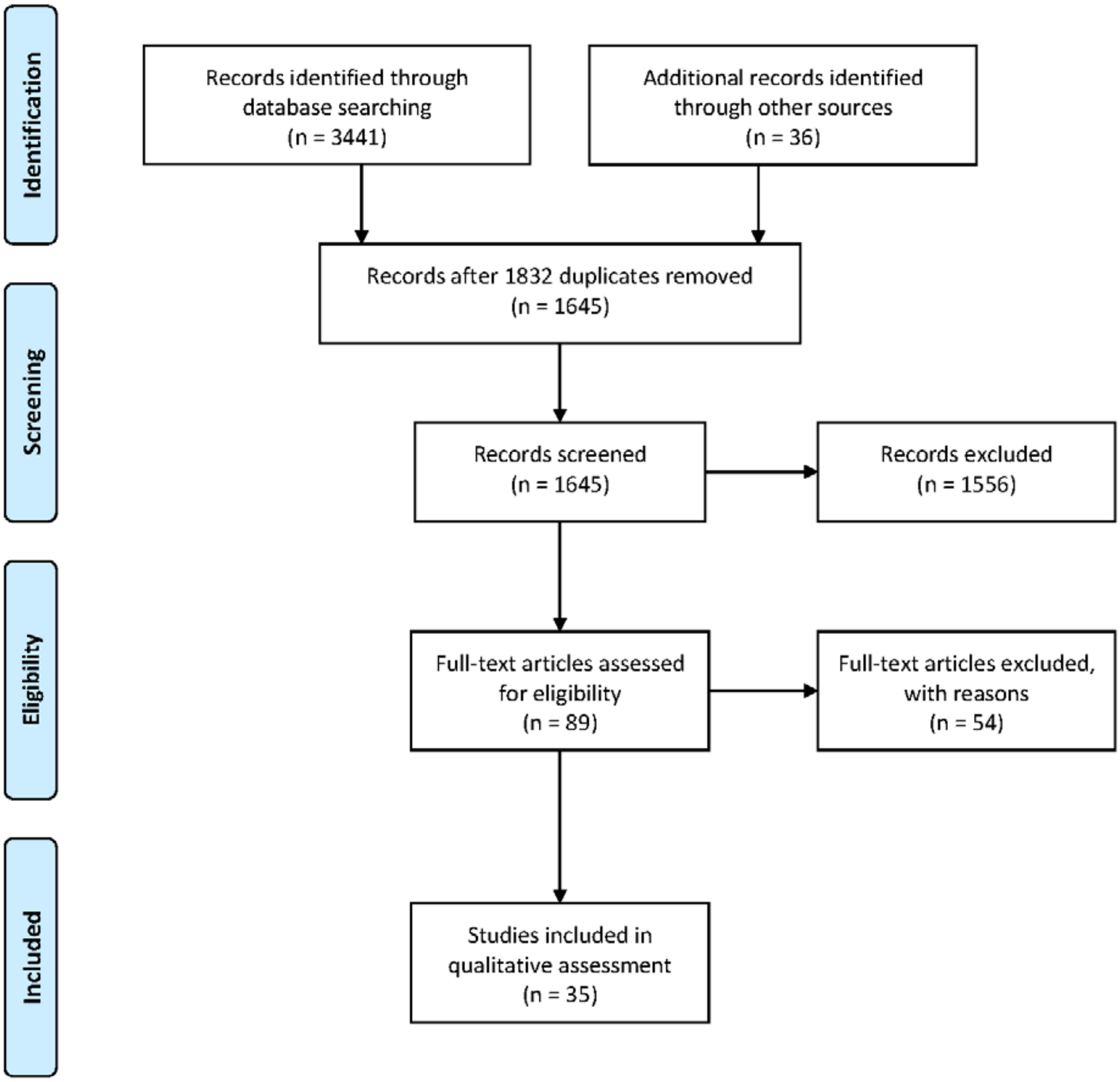
3.3. Results

A peer-reviewed literature search produced 3,441 records of which 1,832 were duplicates with 1,609 articles remaining. Thirty-six other articles or reports were added from other sources resulting in 1,645 unique records in total. A title and abstract search identified 89 relevant articles for a full-length assessment. Finally, independent full-text reading resulted in 35 eligible studies (see Appendix A for the study protocol). Out of the 35 included studies, 11 were peer-reviewed articles and 24 were added from the grey literature.

The 35 eligible studies were published between 1990 and 2018. Twenty-one studies were conducted in Australia, followed by six studies in Canada, three studies in New Zealand, two studies in United States, one study each in Finland, Spain and Sweden.

Overall, 54 documents were excluded from the current systematic review. The reasons these studies were excluded are they did not provide first instance data (Graitcer et al, 1995; Finch, 1996; Robinson, 1996; Robinson, 1998; Robinson, 2005; Robinson, 2006; Wardlaw, 2006; Curnow, 2008; Clarke, 2012; Johnston, 2012; Clarke, 2014; Wang et al, 2014; Olivier et al, 2016), a study that counted injuries and not cyclists (King & Fraine, 1994), no pre- and post-legislation data were available (Harrison, 1994; McDermott, 1995; Rissel & Wen, 2011; Olivier et al, 2013), studies for which only an abstract was available (Karkhaneh et al, 2010), studies with no relevant data to the current systematic review (Vulcan et al, 1992; Hall, 1997; Waterston, 1997), and studies that were commentaries, reviews, response letters or articles with no data reported (DeMarco, 1994; Keatinge, 1994; Minerva, 1996; Davis & Pless, 1996; Unwin, 1996; Davis, 1997; Hillman, 1997(a); Hillman, 1997(b); Keatinge, 1997; Pless & Davis, 1997; Robinson, 1997; Shield, 1997; Acton, 1998; Carnall, 1999; Macpherson & Parkin, 2003; Robinson, 2003; Curnow, 2005; Clinch, 2006; Geary, 2006; Hagel et al, 2006; Hagel & Pless, 2006; Raven, 2006; Elbers & Van Enst., 2010; Olivier et al, 2012; Rissel & Wen, 2012; Hagel & Yanchar, 2013; Rojas-Rueda et al, 2013; Walter et al, 2013; Watkins & Mindell, 2013; Bateman-House, 2014; Olivier, 2014; Attard et al, 2016).

Figure 3.1. PRISMA Flowchart for the systematic review of the impact of BHL on cycling



The large proliferation of commentaries gives the impression the effects of bicycle helmet legislation is an often-debated topic. However, many of them are inter-related with the same authors from both sides of the argument writing multiple letters to those on the other side.

One such discussion in the British Medical Journal (BMJ) was initiated by Minerva (1996) who, in response to another commentary by Unwin (1996), stated she “is a keen cyclist but does not like wearing her helmet”. Davis and Pless (1996) responded calling for robust evidence to support or refute the argument bicycle helmet legislation deters cycling. This was followed by letters from Davis (1997), Waterston (1997), Robinson (1997), Keatinge

(1997), Hillman (1997), and Hall (1997) who give various arguments bicycle helmet use should not be legislated. Many of the responders cited Robinson (1996), published in another journal, as evidence to support their position (Dorothy Robinson was curiously not one of the citers). Pless and Davis (1997) then responded to the responses with Hillman (1997) offering a second response. Shield (1997), writing in another journal, discusses this series of commentaries suggesting injury researchers should anticipate consequences and challenges to proposed interventions such as bicycle helmet legislation.

A decade later in BMJ, Hagel et al (2006) and Robinson (2006) offer pro and con sides to the bicycle helmet debate. This was followed by comments on the against side from Geary (2006), Raven (2006), and Clinch (2006). Similar back-and-forth discussions can be found in Injury Prevention (Robinson, 2003; Macpherson et al, 2003), the Health Promotion Journal of Australia (Olivier et al, 2012; Rissel & Wen, 2012), New Zealand Medical Journal (Clarke, 2012; Wang et al, 2014; Clarke, 2012) and Gaceta Saniteria (Rojas-Rueda et al, 2013; Suelves, 2013; Olivier, 2014). In total, 26 out of 55 excluded studies were parts of six debates occurring over the span of two decades.

Summaries of the included studies are provided below. These summaries have been grouped by country and jurisdiction in chronological order of legislation start date.

3.3.1. Cycling in Australia

This systematic review identified twenty studies conducted in Australia. This includes three Victorian studies, five from Western Australia, one from South Australia, six from New South Wales, and one from the Northern Territory. There are also four Australia-wide studies.

Victoria

Bicycle helmet legislation was introduced on 1 July 1990 for cyclists of all-ages in Victoria. A series of four surveys were conducted in metropolitan Melbourne by the Monash University Accident Research Centre (MUARC) (Cameron et al, 1992; Finch et al, 1993; Cameron et al, 1994). These surveys were designed to estimate helmet wearing by direct observation at fixed locations and were conducted in Nov 1987 - Jan 1988, May 1990, May 1991, and May 1992 for three age groups (5-11 years old, teenagers, and adults). No adult data was collected in 1990.

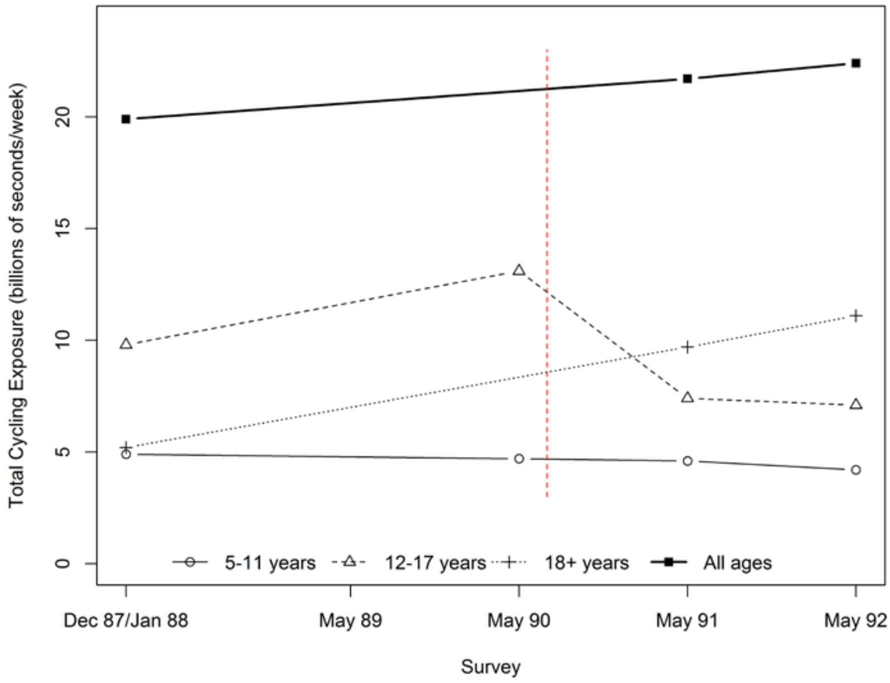
The numbers of observation sites, numbers of cyclists, and cyclists observed per site is given below in Table 3.1. The number of observed cyclists declined following legislation, but this could be due to an existing trend as there was a decline from the first and second surveys prior to legislation. However, caution should be taken in overinterpreting these results since these surveys were not always taken in the same month and the number of observation sites changed over the years.

Table 3.1. Data collected at fixed observation sites in Melbourne from 1987/88-1992 (source: Cameron et al, 1994)

Survey	Observation sites	Cyclists	Cyclists/site	Helmet wearing
Nov 1987 – Jan 1988	105	5837	55.6	24
May 1990	80	3709	46.4	31
May 1991	64	2011	31.4	64
May 1992	64	2477	38.7	76

Across the four surveys, billions of seconds cycling was estimated for the three age groups (see Figure 3.2). Following BHL, there were noticeable declines in cycling exposure for teenagers; however, cycling exposure increased during the study period overall due to a large increase in adult cycling. There was a slight decline in children cycling, although this may have been part of an existing trend.

Figure 3.2. Age-specific estimated bicycle use in metropolitan Melbourne:1987/88-1992 (source: Finch et al, 1993)

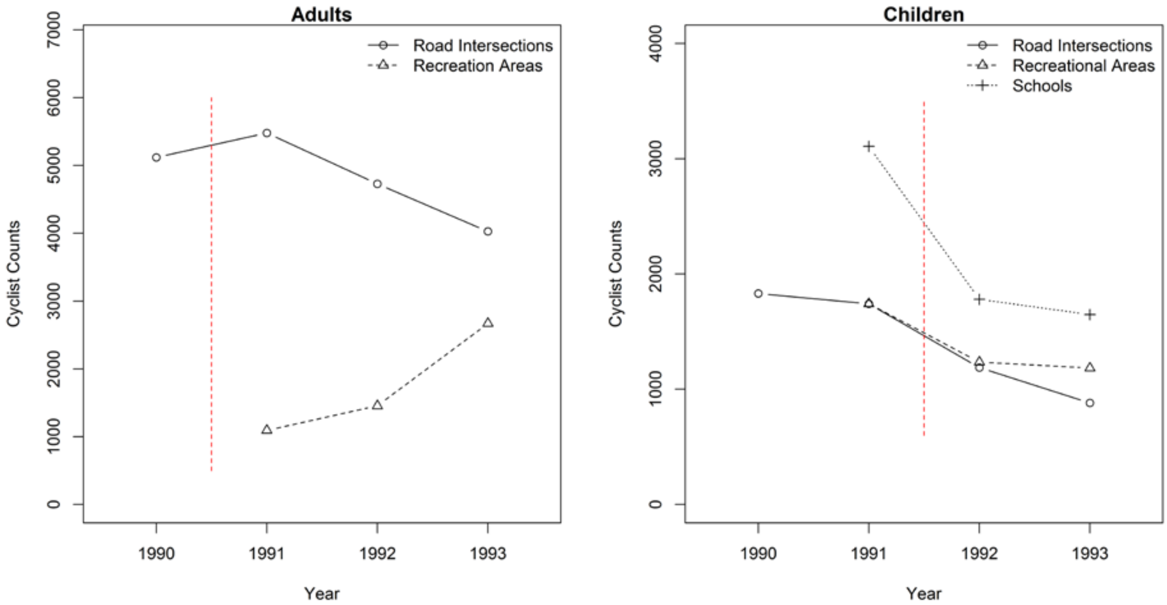


New South Wales

Bicycle helmet legislation was first introduced in New South Wales (NSW) on 1 January 1991 for cyclists aged 16 years and older (Smith & Milthorpe, 1993). The law was modified six months later to apply to cyclists of all-ages. A series of four helmet use surveys were undertaken from 1990-1993 (Walker, 1990; Walker 1991; Walker, 1992; Smith & Milthorpe, 1993). The first survey was conducted in September 1990, while the remaining surveys were conducted in April of their respective years.

The number of observation sites differed across the surveys with 122 used in the final survey and 78 in the first. This included 72 locations in the Sydney metropolitan area and 50 locations in rural centres throughout New South Wales. Three types of sites were chosen to conduct the observations including road intersections, school gates and recreational sites such as parks and beaches. The aggregated cycling counts observed for adults and children at road intersections, and children in recreational areas and children cycling to school are presented in Figure 3.3. Note that data from Albury, NSW is not included in this figure since this location was not included in all surveys.

Figure 3.3. Counts of cyclists in NSW from 1990-1993 (source: Smith & Milthorpe, 1993)



The counts of adult cyclists increased following the first NSW law in January 1991, while there was a decline in children cycling across all area-types following the all-ages law in July 1991. The reduction in adult cycling counts at road intersections after legislation may be a concern as it could be suggested the deterrent effect of legislation was delayed. However, the counts of adult cyclists in recreation areas increased during this time from 1095, 1456, and 2671 for years 1991, 1992 and 1992 respectively.

The aggregated cycling count data may be an indication of fewer child cyclists following BHL; however, Smith and Milthorpe (1993) argue their data should not be used for that purpose due to the study design (see Figure 3.4). Despite the authors' warning, some authors have used the data found in these reports as evidence bicycle helmet legislation deters cycling (Robinson, 1996; Robinson, 2003; Rissel & Wen, 2011; Clarke, 2012; Lemon, in press).

This point is made clear when considering the initial survey design and objectives and with how later surveys proceeded. The three study objectives of Walker (1990) were (1) to “estimate helmet wearing and law violation rates”, (2) to “provide base-rate data on helmet wearing” prior to legislation, and (3) to “obtain information on demographic and environmental factors” associated with helmet wearing. Additionally, the initial survey included observation sites commonly used by cyclists (bicycle paths, cycling parks and arterial roads). These locations were not used in subsequent surveys, although these locations observed the most cyclists overall and on a per-site basis prior to legislation. The exclusion of these locations from further surveys may be related to the study objectives to estimate helmet wearing and not to estimate cycling exposure.

Figure 3.4. Caution about using findings of NSW surveys (source: Smith & Milthorpe, 1993)

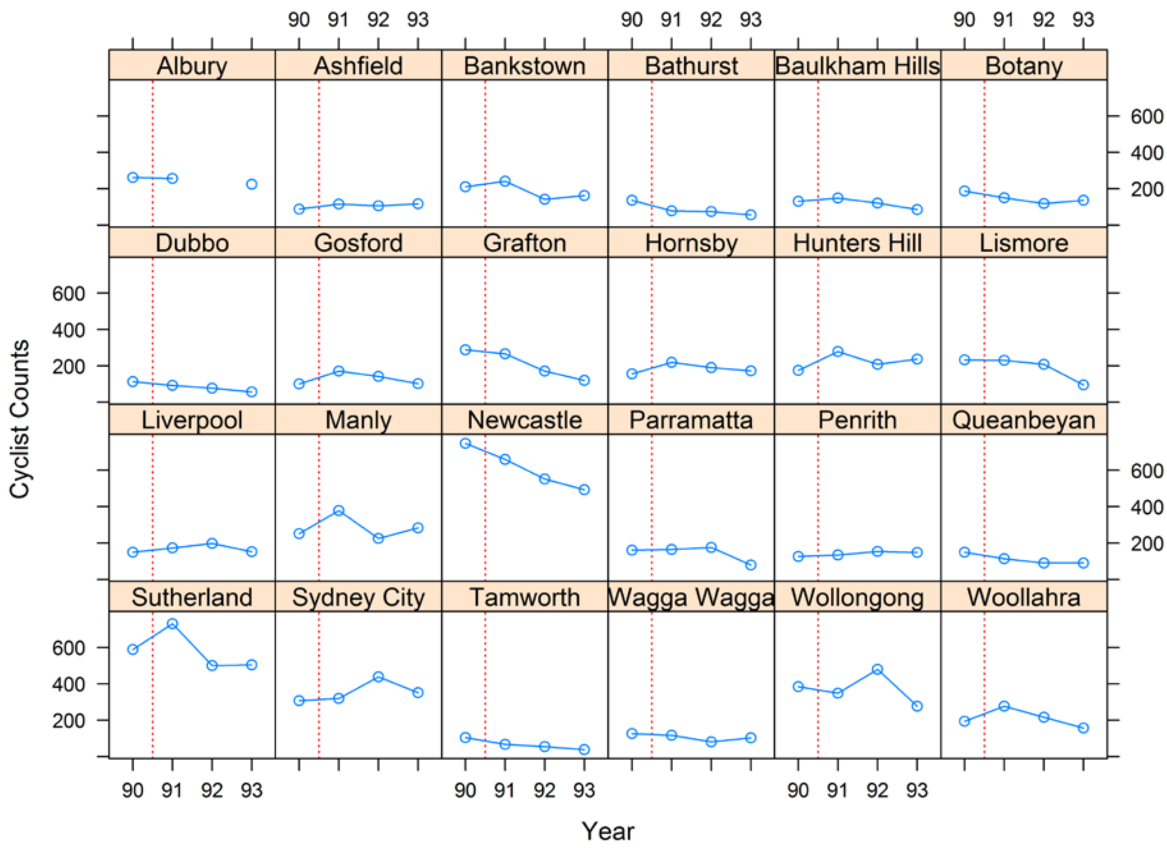
the school sites surveyed in Sydney (~30%). However, care must be taken in interpreting the figures in the report as overall community cycling rates. The Sydney road sites were originally selected by road place and type rather than by cycle route, therefore numbers of cyclists counted in the road surveys will be a more conservative count than had sampling been carried out by cycle route. Similarly the school sites were sampled geographically rather than by school attitude to cycling which is a dominant factor in ridership thus some schools with low ridership have been included in the sample. (School attitudes may also have an effect on helmet wearing).

Therefore these figures should not be used to estimate total exposure or ridership in the State of New South Wales.

The data from these surveys is also limited due to coverage bias, that is, there were likely too few observation locations to adequately capture the NSW cycling population at that time. For example, the 1991 estimated population of the Newcastle statistical district was 444,900 residents, yet only four road intersections were surveyed (ABS, 1991; Walker, 1991). Similarly, Wollongong’s 1991 population was an estimated 244,900 residents and only two road intersections were surveyed. By comparison, Macpherson et al (2001) observed child cyclists at 111 locations in East York, Ontario which had 22,765 residents under 18 years of age at the 1996 Census (Statistics Canada, 1996). Note this issue is irrespective of whether direct observation of cyclists is a valid measure of cycling exposure.

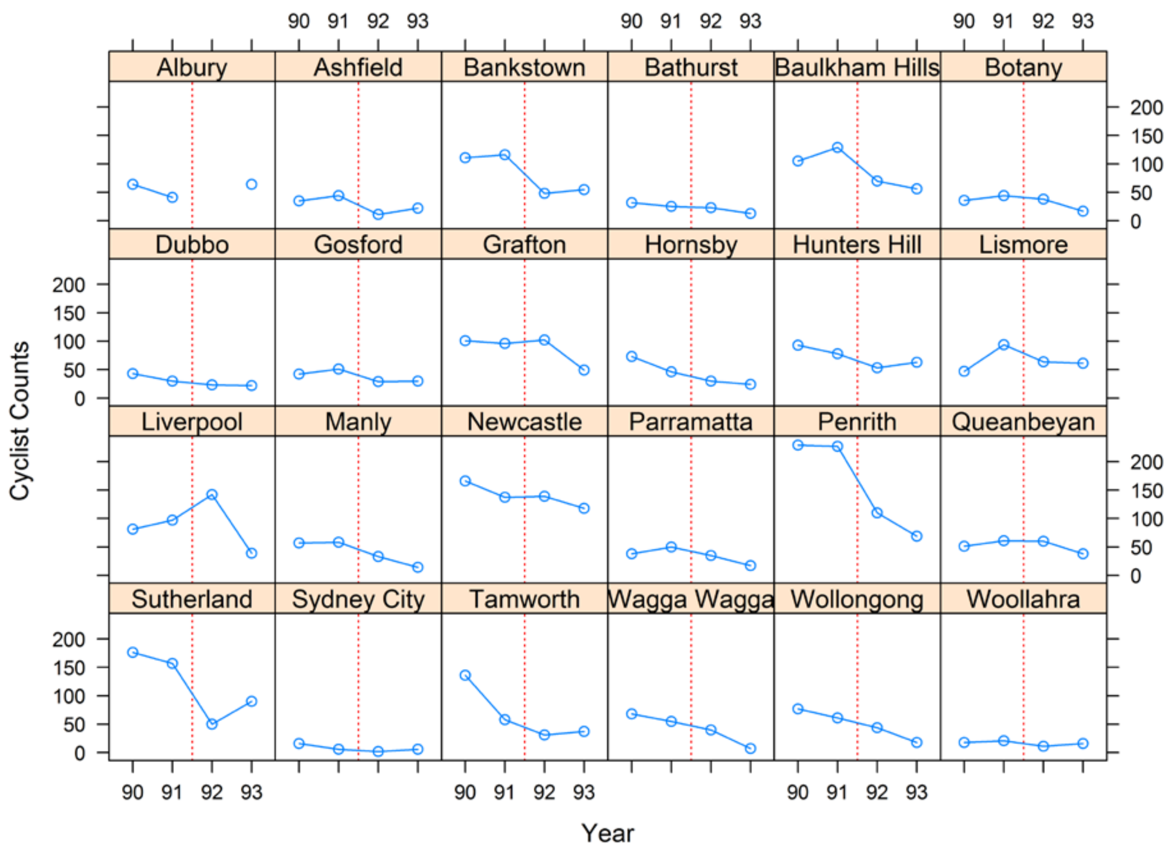
The study authors further indicate data was collected during school holidays when there is a reduction in commuter and tertiary school cycling (Smith & Milthorpe, 1994). The authors also discuss inconsistencies in observations across sites and suggest there may be multiple reasons for the observed reduction in child cycling counts. With that in mind, the counts of adult and child cyclists at each location from the NSW surveys are given in Figures 3.5-3.8.

Figure 3.5. Counts of adult cyclists at road intersections in NSW from 1990-1993 (source: Smith & Milthorpe, 1993)



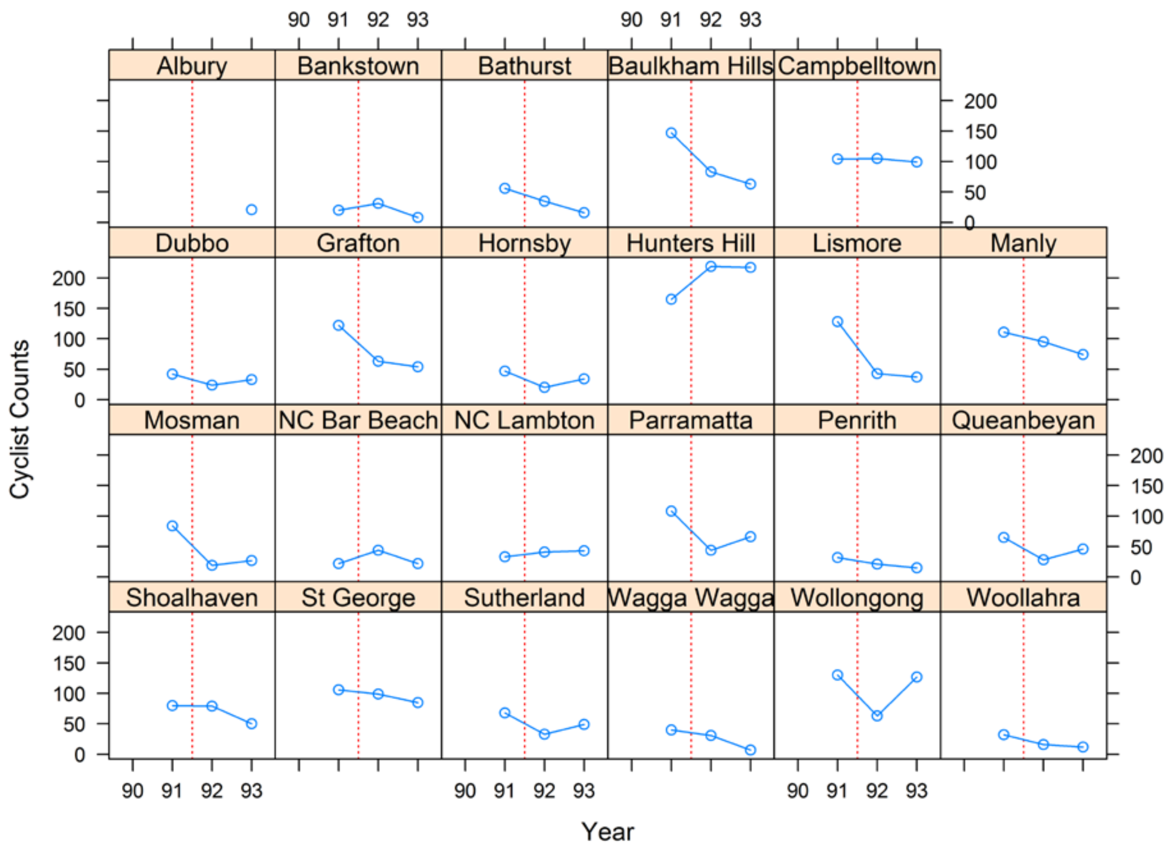
There was only one survey conducted prior to BHL for NSW adults, so it is not possible to estimate existing trends. However, only seven out of twenty-four locations observed sustained reductions in cycling counts following legislation. This includes Bathhurst, Botany, Dubbo, Grafton, Newcastle, Queanbeyan, and Tamworth. More locations observed increases in cycling counts following legislation.

Figure 3.6. Counts of child cyclists observed at intersections in NSW from 1990-1993 (source: Smith & Milthorpe, 1993)



Unlike data on counts of adult cyclists, two helmet use surveys were conducted prior to legislation for children under 16 years of age. With regards to child cyclists observed at road intersections, there were noticeable reductions at eight locations including Ashfield, Bankstown, Baulkham Hills, Lismore, Manly, Parramatta, Penrith, and Sutherland. There were reductions at seven other sites including Bathurst, Dubbo, Hornsby, Hunters Hill, Tamworth, Wagga Wagga and Wollongong; however, these reductions appear to have been the continuation of an existing trend. Additionally, it is not clear whether the observed patterns are due to natural variability. The Lismore counts, for example, appear to decline following legislation; however, both post-legislation observations are greater than the 1990 count. Immediate reductions were not observed at the remaining nine locations.

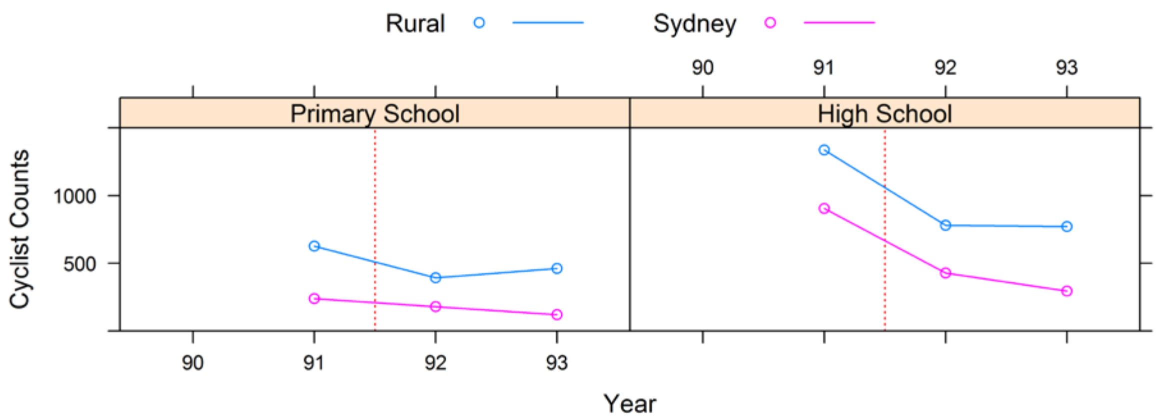
Figure 3.7. Counts of child cyclists at recreation areas in NSW from 1990-1993 (source: Smith & Milthorpe, 1993)



Data collected at recreational areas was not conducted during the first survey in 1990; therefore, it is not possible to assess the impact on adult recreational cyclists or to estimate existing trends for child recreational cyclists. Sustained reductions in the count of child cyclists were observed at eleven locations including Bathurst, Baulkham Hills, Grafton, Lismore, Manly, Mosman, Parramatta, Penrith, St George, Wagga Wagga, and Woollahra. Unlike data collected at road intersections, it is not possible to assess whether these reductions were part of existing trends. Other locations such as Dubbo, Hornsby, Queanbeyan, Sutherland and Wollongong observed reductions in child cycling counts immediately following legislation and then a recovery by the next survey.

When individual locations from the NSW surveys are considered, other inconsistent patterns emerge. There were observed reductions in child cyclists at Lismore road intersections and recreational areas; however, there is no substantial reduction in adults in Lismore for the first two surveys post-legislation. Children at recreational areas and adults at road intersections in Hunters Hill increased dramatically following legislation, but the opposite was observed for children at road intersections. Adult cyclists in Manly appear to have been largely unaffected by legislation, although there were observed reductions in child cyclist counts.

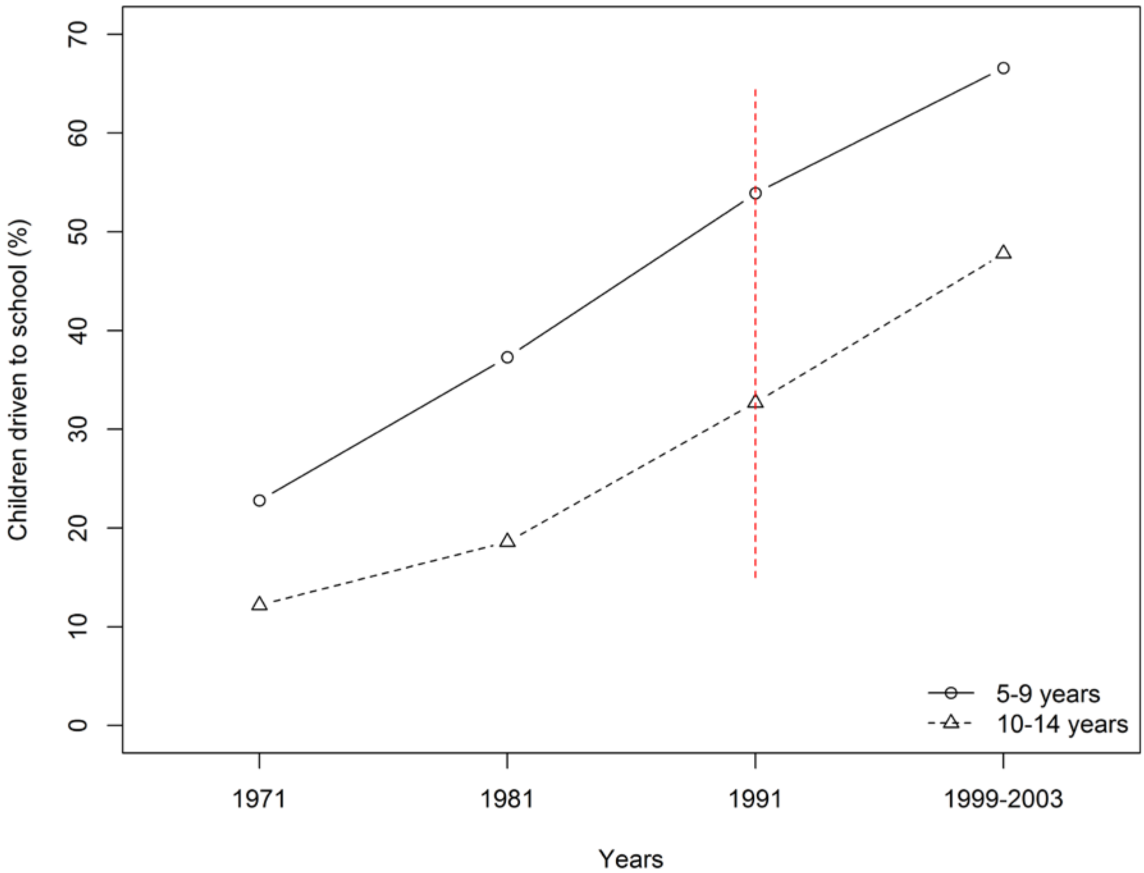
Figure 3.8. Counts of children cycling to school in NSW from 1990-1993 (source: Smith & Milthorpe, 1993)



There were reductions in the counts of children cycling to school following legislation irrespective of location (Sydney vs Rural) or school type (Primary vs High School). Data was collected at school gates for all four surveys; however, the number of schools increased from 24 to 59 from the first and second surveys. Additionally, the data has been aggregated by location and school type making it impossible to compare trends for the 24 schools observed across all four surveys. The data from the first survey, therefore, has not been included.

The reduction in children cycling to school in NSW is likely due to an increase in motor vehicle travel which began prior to BHL. The results from NSW household travel surveys from 1971, 1981, 1991 and 1999-2003 are given in Figure 3.9 (van der Ploeg et al, 2008). Across the four surveys, the authors note that cycling to school was not common (1-2%).

Figure 3.9. Estimated proportion of NSW children driven to school from 1971-2003 (source: van der Ploeg et al, 2008)



In a later study, Walter and colleagues (2011) used NSW hospitalisation data to assess the impact of BHL on cycling head injuries. Routine data collection of all hospitalisations for NSW residents began in July 1988 (the beginning of the Australian financial year). This database is a census of those admitted to a NSW hospital and for NSW residents who were hospitalised in other Australian states. The first year of NSW hospital data included only one diagnostic field, so Walter et al (2011) excluded data for this year since cyclists presenting with multiple injuries were not accurately recorded during this time. To minimise the effect of multiple counting, hospital records coded as transfers, type changes and deaths were excluded.

Diagnoses were coded using International Classification of Diseases version 9, Clinical Modification (ICD-9-CM) for financial years 1988-1999 and ICD-10-AM (Australian Modification) since 1997. There was a two-year period when diagnoses were coded using both ICD versions. Walter el al (2011) identified injuries in ICD-9-CM that corresponded to ICD-10-AM codes by body region. For example, head injuries in ICD-10-AM are in the range S00-S09 and approximately correspond to ICD-9-CM codes 800–804, 850–854, 870–873, 830, 910, 918, 920, 921, 925.1, 930–932, 950, 951, 957.0, and 959.0. Note that some ICD-9-CM codes combined head and neck injuries, so it is not possible to completely map injuries between these coding schemes. However, Walter et al (2011) found these injuries to be rare and head injury rates were similar for years 1997-1999 when both ICD coding schemes were used.

The NSW hospital data has clear strengths over direct observation of cyclists at fixed locations over a short time frame. The hospital data is a complete data set – includes all hospitalised cyclists with usable data collected continuously since July 1989 – while the NSW helmet use surveys are limited by missingness (only 20 hours of observation per site per year) with the first survey collected in September 1990, and these surveys are likely influenced by selection and coverage biases due to fixed locations that excluded known cycle routes.

Using NSW hospital data, a series of interrupted time-series models were utilised for cycling head injury per 100,000 population and controls selected from time series of arm and leg injuries for cyclists. Limb injuries can be considered a quasi-induced measure of exposure since these injuries should not be affected by increased helmet usage but would be affected by potential reductions in cycling. From the pre- to post-BHL periods, cycling limb injuries would be unaffected by increased helmet usage but would artefactually decline if there was a reduction in cycling exposure. Using model estimates from Table 2 of Walter et al (2011), the estimated rates of cycling arm injuries (-11%; 95% CI: -27%, +10%; p=0.28) and leg injuries (-6%; 95% CI: -27%, +21%; p=0.62) changed very little following BHL.

South Australia

Bicycle helmet legislation in South Australia (SA) began on 1 July 1991 for cyclists of all ages (Marshall & White, 1994). This was preceded by television, radio and print media helmet promotion campaigns beginning in 1985. A bicycle helmet rebate scheme ran from November 1989 to April 1991 where 17,123 rebates were issued.

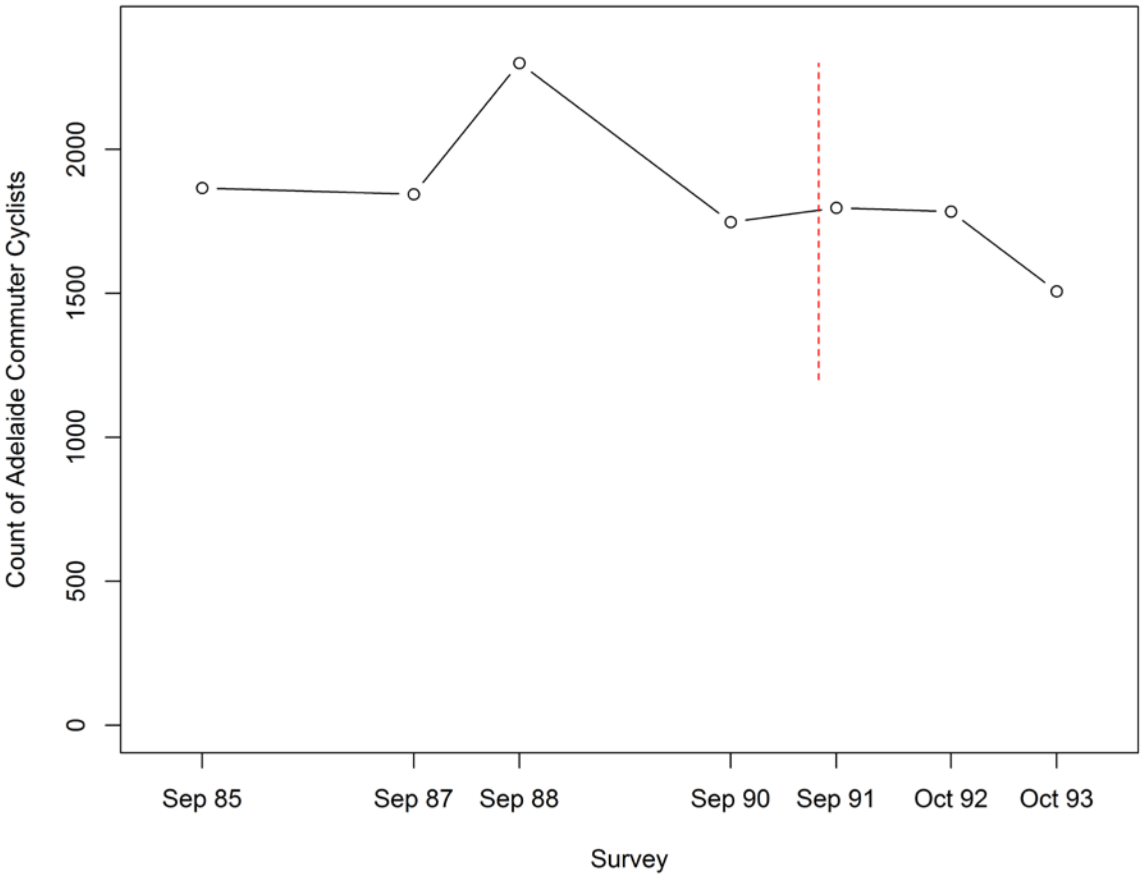
Two household surveys were conducted on SA residents aged 15 or older from approximately 3000 households in 1990 and 1993. Cycling frequency for a child under 15 years was also collected for each household where possible. Stratified random sampling of households was used to identify the sample. As presented in Table 3.2, there was very little change in self-reported frequency of bicycle riding between 1990 and 1993, for both males and females and for children and adults.

Table 3.2. Frequency of cycling in South Australia by gender and age in 1990 and 1993 (source: Marshall & White, 1994)

	Males, 15+		**Females, 15+**		**Males, <15**		**Females, <15**	
Frequency	**1990**	**1993**	**1990**	**1993**	**1990**	**1993**	**1990**	**1993**
At least weekly	17.0%	15.4%	7.7%	7.0%	65.4%	70.6%	55.2%	51.3%
At least monthly	5.5%	6.7%	4.3%	4.2%	5.7%	7.9%	7.3%	10.1%
At least every 3 mos	4.8%	6.2%	3.8%	3.6%	2.3%	2.0%	2.4%	4.4%
Less often or never	72.5%	71.7%	84.0%	85.2%	26.6%	19.5%	34.7%	34.2%

Counts of commuter cyclists into Adelaide were collected from September 1985 until October 1993 (Marshall & White, 1994). This was primarily adult cyclists, although some children were also counted. The deviation from a flat trend in 1988 and 1993 may be artefactual. The recording method was modified for only the 1988 survey to include all cyclists in view of observers and the 1993 count was affected by poor weather. There was a 2.9% increase in the count of commuter cyclists from the surveys immediately prior and following legislation.

Figure 3.10. Counts of Adelaide commuter cyclists from 1985 to 1993 (source: Marshall & White, 1994)

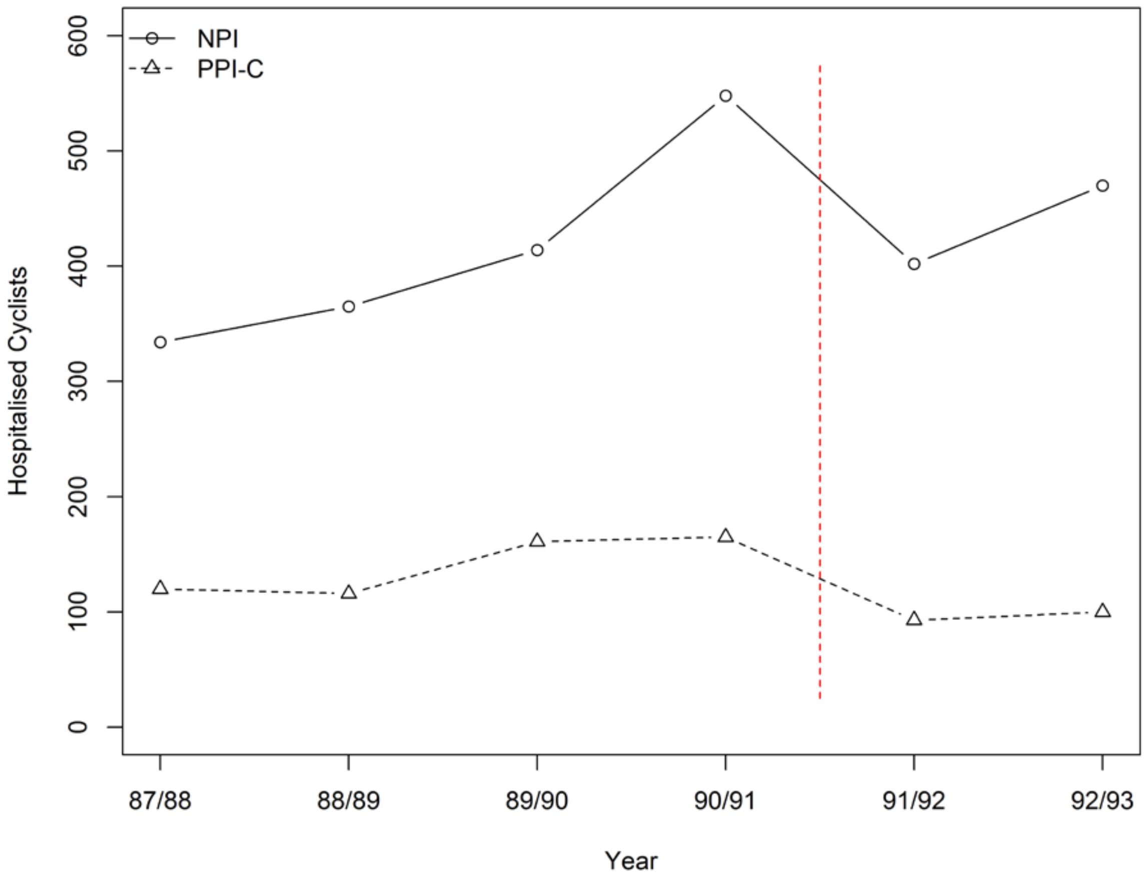


The study authors reported reductions in cycling from two sources: surveys of children cycling to school and trends in cycling hospitalisations. Harrison (1994) conducted a survey of SA children cycling to school in 1994. The authors report the study was designed to observe 2200 cyclists from 85 schools using estimates collected in a 1988 study by the same author. The author observed 1,455 students cycling to school and thus concluded a 38.1% reduction in SA children cycling to school from what was expected by the study design. A search could not locate the 1988 report and current representatives of Harrison Research have no record of the report[1]. Hence, it was decided to exclude these results from this review unless the 1988 report can be identified to verify the study results.

[1] Harrison Market Research changed ownership in 2003 and very few records exist prior to that date.

Marshall and White (1994) reported yearly sums of hospitalised cyclists in SA. Each cyclist was categorised as having either a potentially preventable injury if a helmet was worn (PPI), a non-preventable injury (NPI), or a concussion (C). Note that injuries were defined by International Classification of Disease (ICD) codes and each cyclist is counted once such that NPI cyclists have no PPI or C injuries. ICD codes used to define PPI injuries are given in Appendix 1 of Marshall and White (1994). Admission practices regarding concussions changed during this period (Laurie, 1992), so this data is not presented here and those with only concussions have been excluded from potentially preventable injuries (denoted PPI-C). The trends in cycling hospitalisations are presented in Figure 3.11.

Figure 3.11. South Australia hospital admissions by type of injury from July 1987 to June 1993 (source: Marshall & White, 1994).



Cycling hospitalisations categorised as preventable declined following bicycle helmet legislation; however, there was also a decline in non-preventable hospitalisations. The reduction in NPI hospitalisations could be taken as evidence of reduced cycling following BHL in South Australia. However, there appear to be omissions in the definition of preventable injury (see Table 3.3). ICD codes not defined as PPI include skull fractures (804.1-804.99), unspecified intracranial injury (854.19), open wound of ear (871.2), superficial head injuries (910) or middle/lower-face injuries (873.4-873.9). That is, the control time series NPI may have been influenced by increased helmet usage and not necessarily fewer cyclists.

Table 3.3. International Classification of Disease, 9th Revision (ICD9) codes for head injury by inclusion in definition of potentially preventable injury (source: Marshall & White, 1994)

ICD9 Range	Injury Description	Included in PPI Definition
800.00 to 802.10	Skull and nasal bone fractures	Yes
802.11 to 802.39	Fracture of face bones	No
802.40 to 804.06	Upper facial bone fractures	Yes
804.07 to 849.99	Fracture of skull or face	No
850.00 to 854.16	Brain injury (without skull fracture)	Yes
854.19	Intracranial injury of other and unspecified nature	No
870.00 to 871.90	Injury to eye, eyeball	Yes
871.2 to 872.99	Open wound of ear	No
873.00 to 873.39	Open wound of scalp, nose	Yes
873.42	Open wound of forehead	Yes
873.52	Open wound of forehead	Yes
873.4-873.9	Open wound of head	No
910	Superficial injury of face, neck and scalp	No
918	Superficial injury of eye and adnexa	No
920-921	Contusion of face, scalp, neck, and eye	No
925.1	Crushing injury of face and scalp	No
930-932	Effects of foreign body entering through orifice	No
950, 951, 957	Injury to optic nerve and pathways, other cranial nerve, other and unspecified nerves	No

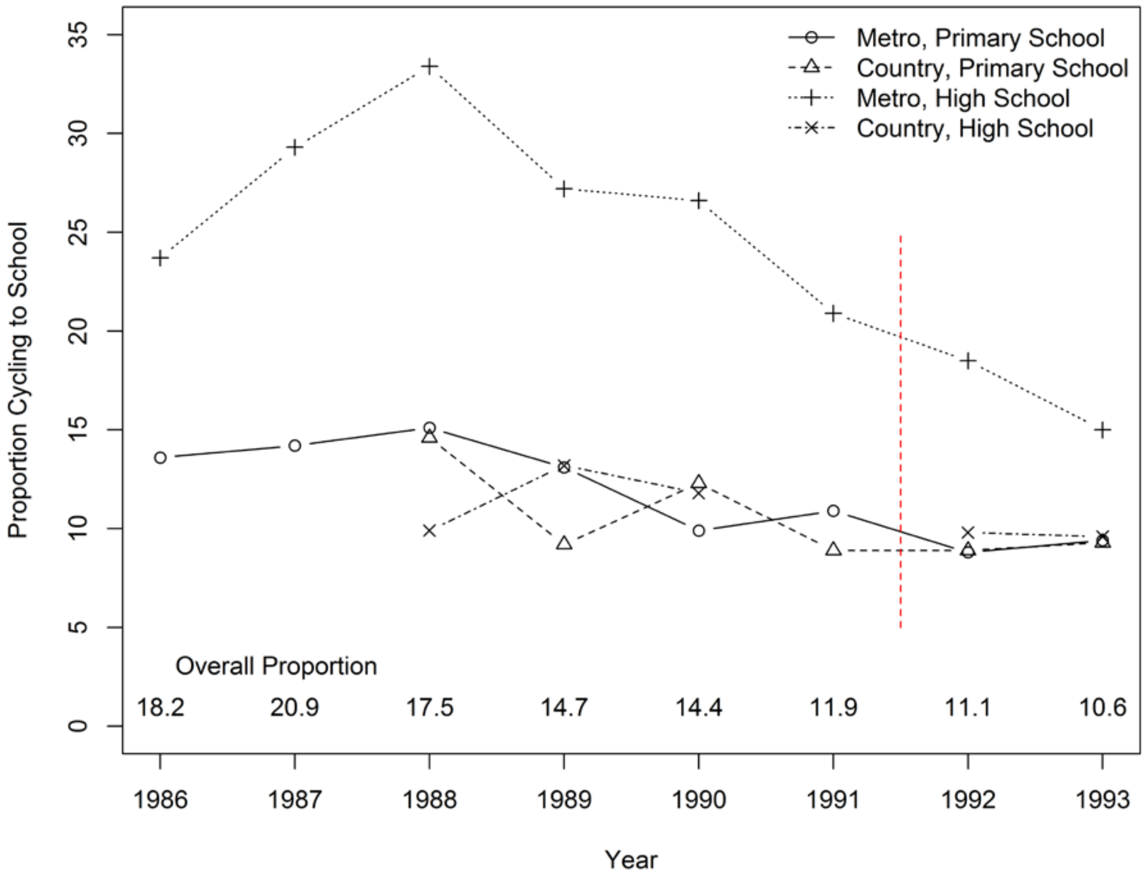
*Missing ranges of ICD codes in Marshal & White (1994) paper are shaded

Western Australia

Bicycle helmet legislation in Western Australia (WA) commenced from 1 January 1992 for cyclists of all-ages (Healy & Maisey, 1992). There were no fines during the first six months of legislation; however, the police issued approximately 3000 official cautions during this time (Healy & Maisey, 1992). Starting 1 July 1992, cyclists could be issued a $25 fine for non-compliance with the law. Until December 1992, those issued fines could have them withdrawn if proof of a helmet purchase was provided to the police within two weeks (Heathcote, 1993). During the second six-month period of BHL in WA, 14% (553/3939) of cyclists stopped by the police for non-compliance were issued a fine that was not later withdrawn (Healy & Maisey, 1992; Heathcote, 1993). A bicycle helmet meeting the Australian standard could be purchased for $55 and were half-priced ($27.50) the month prior to legislation (Healy & Maisey, 1992).

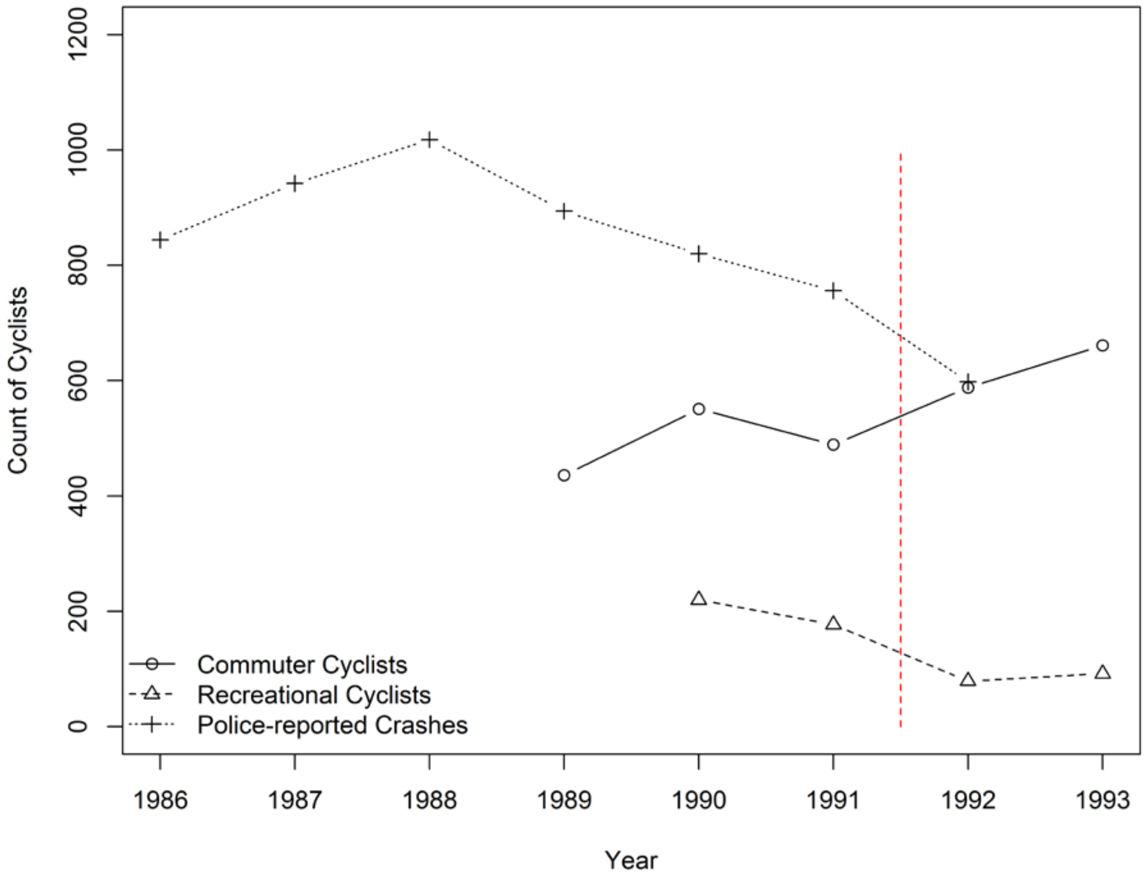
A series of surveys were undertaken to collect data on children cycling to school (primary and high school), commuter cyclists and recreational cyclists (Healy & Maisey, 1992; Maisey, 1993; Heathcote, 1993). There was a steady decline in the proportion of WA children cycling to school from 1988 (see Figure 3.12). There was a slight decline in this proportion following bicycle helmet legislation; however, this appears to have been part of an existing trend.

Figure 3.12. Proportion of children cycling to school in Western Australia 1986-1993 (source: Heathcote, 1993)



The counts of commuter and recreational cyclists in WA are given in Figure 3.13. During the study period, cyclists categorised as “commuters” increased while counts of recreational cyclists decreased. The number of cyclists in a police-reported crash has also declined during this time and appears to be part of an existing downward trend.

Figure 3.13. Counts of commuter cyclists, recreational cyclists, and police-reported crashes involving cyclists in Western Australia (source: Heathcote, 1993)



Bicycle counters were placed on two Perth cycleways, the Narrows and Causeway bridges, prior to legislation in September 1991 (Heathcote, 1993). The counts of cyclists at these locations declined by 38.3% when comparing Oct-Dec 1991 to Oct-Dec 1992 (24,932 vs 13,336).

Due to the decline in counts of cyclists by direct observation at fixed locations from past surveys, a fourth report was commissioned to estimate the impact of bicycle helmet legislation on cycling from a representative sample of WA residents (Heathcote and Maisey, 1994). This survey used stratified random sampling to collect data on 677 responders from 254 households (150 from Perth metropolitan area and 104 from country areas) in 1993. These results were then compared to a similarly conducted survey by the Australian Bureau of Statistics in 1989. The estimated frequency of WA residents cycling was similar following bicycle helmet legislation in 1993 compared with the frequency prior to legislation in 1989 (see Table 3.4). Note that the percentages have been adjusted to create a non-cycling category (denoted “Never” in the table) using data presented in this report.

Table 3.4. Frequency of bicycle use in Western Australia in 1989 and 1993 (source: Heathcote & Maisey, 1994)

	Survey	
Frequency	**1989**	**1993**
At least weekly	26.6%	27.7%
At least every 3 months	11.1%	11.6%
At least once per year	10.3%	11.5%
Never	52.0%	49.2%

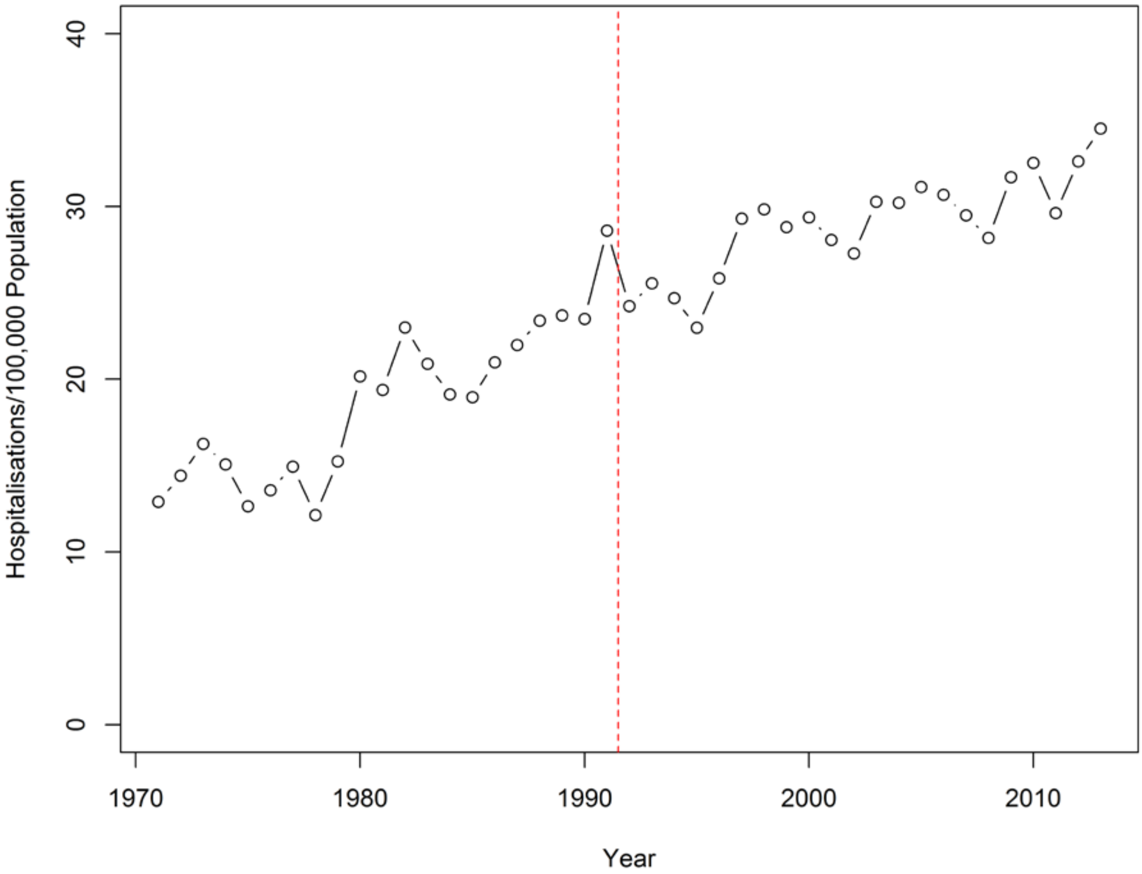
Western Australia hospital data can be used as a measure of quasi-induced exposure and is available electronically since the 1970’s. Cyclists admitted to the hospital without injuries to the head, face or neck can be used as a control time series that should be unaffected by increases in helmet wearing but would be affected by decreased cycling. This data was provided by the WA Department of Health for a master’s thesis (Laolert, 2014). During this time, the coding of diagnoses in WA hospitals changed from ICD-8 (1971-1978), ICD-9 (1979-1987), ICD-9-CM (1988-June 1999), and ICD-10 (July 1999-current). Cyclists and their injuries were categorised using the codes given in Table 3.5.

Table 3.5. International Classification of Disease codes used to identify cyclists and injuries to the head, face and neck

	ICD-8	**ICD-9**	**ICD-9-CM**	**ICD-10**
	1971-1978	**1979-1987**	**1988-June 1999**	**July 1999-current**
Bicyclist	E800-E807 (3), E810-E823 (6), E826.1	E800-E807 (3), E810-E825 (6), E826.1	E800-E807 (3), E810-E825 (6), E826.1	V10-V19
Serious Head Injury	N800-N804, N850-N854	800-804, 850-854	800-804, 850-854	S02, S06
Other Head/Face Injury	N830, N848.0, N848.1, N870-N873, N910, N918, N920, N921, N930–N932, N950, N951, N959.0	830, 848.0, 848.1, 870-873, 910, 918, 920, 921, 925.1, 930–932, 950, 951, 957.0, 959.0	830, 848.0, 848.1, 870-873, 910, 918, 920, 921, 925.1, 930–932, 950, 951, 957.0, 959.0	S00-S01, S03-S05, S07-S09
Neck Injury	805.0, 805.1, 806.0, 806.1, 848.2, 874, 900	805.0, 805.1, 806.0, 806.1, 848.2, 874, 900, 925.2	805.0, 805.1, 806.0, 806.1, 848.2, 874, 900, 925.2	S10-S19

The quasi-induced controls were identified as cyclists admitted to the hospital without any diagnosed head, face or neck injuries. The rate of hospitalisations for the quasi-induced controls per 100,000 WA population is given in Figure 3.14.

Figure 3.14. Rate of bicycle-related hospitalisations without a head, face or neck injury in Western Australia from 1971-2013 (source: Western Australia Department of Health)



The rate of cycling hospitalisations without a head, face or neck injury in WA has steadily increased over a forty-year period. There was no sustained reduction in this time series corresponding to the introduction of BHL.

Northern Territory

Bicycle helmet legislation was introduced in the Northern Territory for adults (17+ years) on 1 January 1992 (van Zyl, 1994). This law was modified from 1 July 1992 to apply to cyclists of all ages and again on 1 March 1994 to allow unhelmeted cycling on footpaths or cycle paths for adults (Northern Territory Government, 2017). Bicycle helmet use was promoted for several years prior to legislation (van Zyl, 1994). Surveys of direct observation of primary school, secondary school, and commuter cyclists were conducted in April 1992 and again in August 1992. Recreational cycling was not included due to a lack of resources.

The number of primary school cyclists was similar pre- to post-legislation (987 in April 1992, 995 in August 1992) and there was a decline in secondary school cyclists (931 in April 1992; 595 in August 1992). Data was collected on commuter cyclists, but no counts are provided in the report and the surveys were conducted after the adult helmet law.

Australian-wide Studies

In addition to state-level reports and data, there were three Australian-wide studies with relevant data including a series of travel to work surveys, estimated kilometres of travel in metropolitan areas, and estimated cycling amounts in 1985/86 compared to 2011.

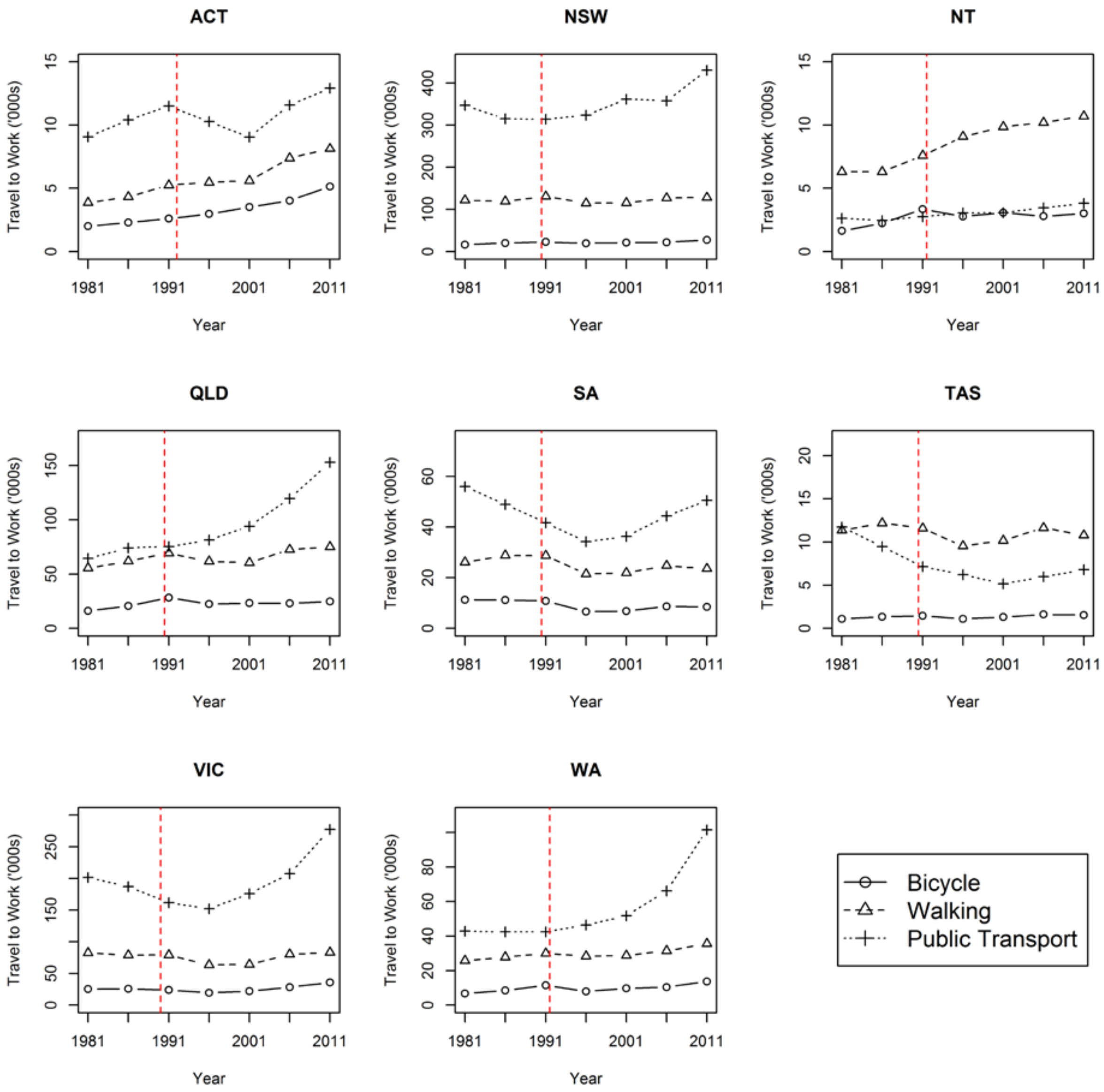
The Australian Bureau of Statistics has collected data on the method of travel to work (MOTW) since 1976 for a single day with observations occurring five years apart (ABS, 2017; Mees & Groenhart, 2012). The census date was on 30 June for years 1976-1986 and ranged from 6-9 August for years 1991-2011. The 1976 data was a 50% sample and not a census due to budgetary restrictions and has, therefore, been excluded.

As part of the survey, responders mark options for travel including (in the following order) train, bus, ferry, tram (including light rail), taxi, car – as driver, car – as passenger, truck, motorbike or motor scooter, bicycle, walked only, worked at home, other, or did not go to work. Multiple responses were allowed and recorded in the order written on the form. It is not possible to indicate a responder's "main mode" of travel since, for example, a person riding a bicycle and a train would always be recorded as "train, bicycle". The responses "did not go to work", "worked at home", and "walked only" are not meant to be part of a multiple response. When this occurs, a single response is recorded with preference in the order they appear on the form. For example, someone responding with “did not go to work” and “walked only” is recorded as “did not go to work”.

MOTW data has been provided by the Australian Bureau of Statistics for years 1976-2001 while data for 2006 and 2011 was extracted from the ABS website. For the purposes of this review, transport modes have been defined as using a bicycle for any leg of travel (Bicycle), walking only (Walking), the use of a bus, ferry, train or tram for any leg of travel except when a bicycle was used (Public Transport), and the use of a car or truck when neither a bicycle or public transport were used for any leg of travel (Vehicle). The total travellers exclude those who did not go to work, worked at home, or whose mode of travel was unknown.

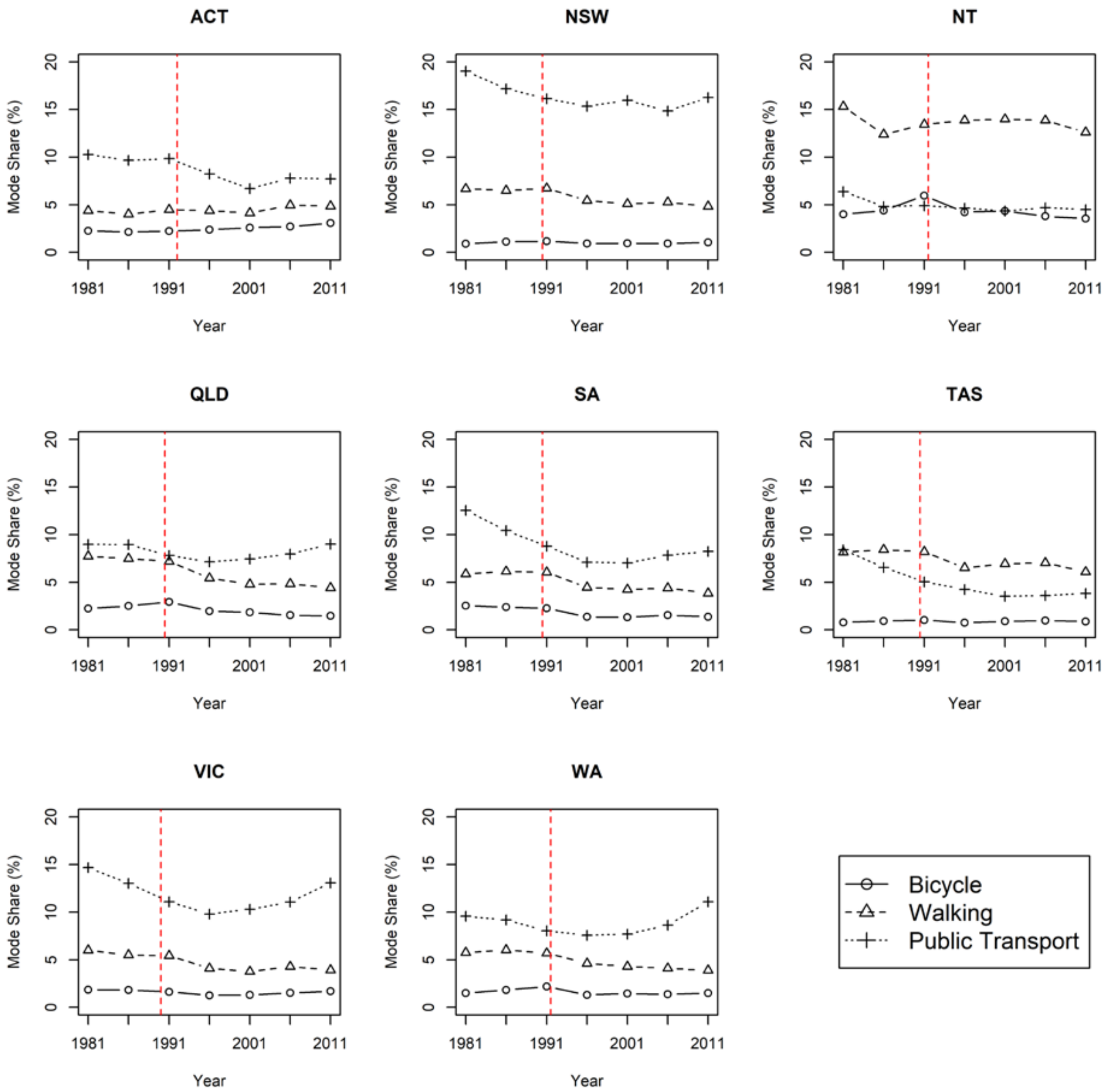
The MOTW data has been organised by state or territory since helmet laws were enacted at those levels. The observed counts and mode share (% of total) are given in Figures 3.15 and 3.16.

Figure 3.15. Number of responses to method of travel to work by active transport modes for Australian states and territories from 1981-2011 (source: Australian Bureau of Statistics)



There were increases in the numbers of responders cycling to work for the ACT, NSW, Queensland and Tasmania following BHL, while the counts were similar for South Australia and Victoria. There were observed reductions for the Northern Territory and Western Australia where each of these jurisdictions introduced BHL after the 1991 census date. This could be due to a general reduction in cycling across Australia as reductions were observed from the 1991 to 1996 censuses for all other jurisdictions except the ACT. Additionally, there were large increases in the use of public transportation since the 1996 census for many jurisdictions which could indicate a shifting among active transport modes.

Figure 3.16. Mode share by active transport modes for Australian states and territories from 1981-2011 (source: Australian Bureau of Statistics)

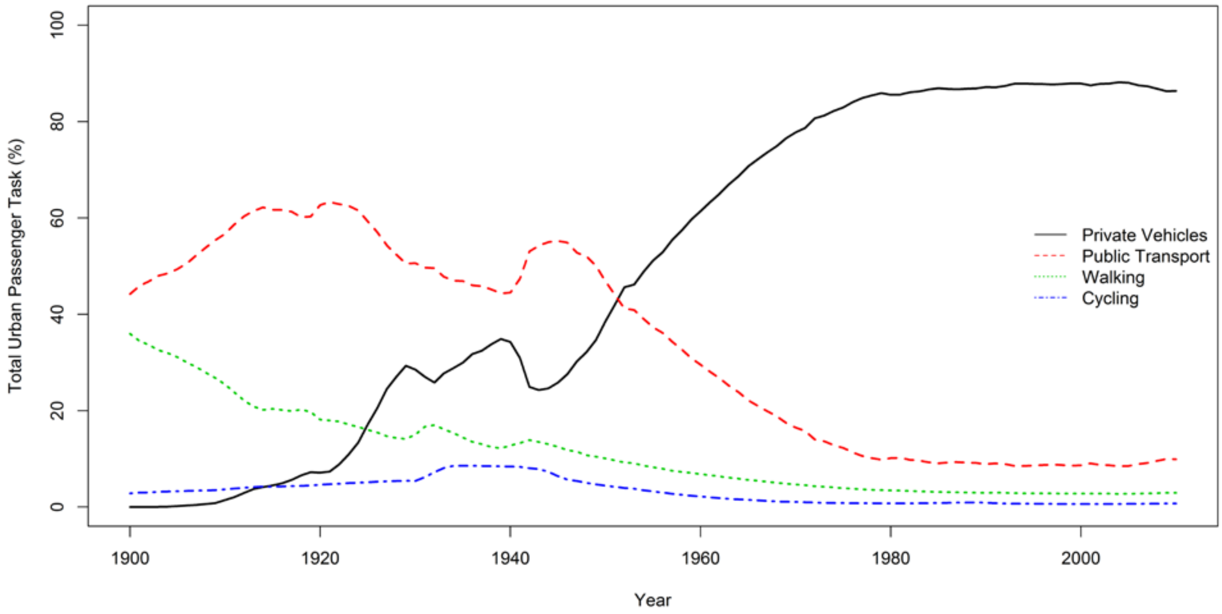


The mode share for cycling to work shows a similar pattern following helmet legislation across Australia. Overall, the numbers who reported using a bicycle for travel to work prior to any helmet legislation was 92,517 in 1986 which increased to 104,470 in 1991 when most of Australia had helmet legislation. Cycling mode share increased slightly between these years as well from 1.74% to 1.84%.

Using data from multiple sources, Cosgrove (2011) estimated the kilometres travelled in Australian metropolitan areas from 1900-2010 for different transport modes (see Figure

3.17). The mode share for cycling peaked around World War II and steadily declined thereafter. Other active transport modes also declined during this time which was due to Australian city design favouring private vehicles and Australians living farther from common destinations such as work, school and shopping (BITRE, 2012). However, Cosgrove (2011) cautions in overinterpreting trends in walking and cycling due to uncertainty in those estimates.

Figure 3.17. Proportion of metropolitan travel by kilometres travelled, by mode, 1900-2010 (BITRE, 2012; Cosgrove, 2011; David Cosgrove, *personal communication*)



Gillham and Rissel (2012) compared two Australian surveys conducted in 1985/86 and 2011 that included data on travel by bicycle (Adena & Monstesin, 1988; Munro, 2011). In comparing these surveys, the authors conclude cycling exposure in Australia had declined over this time frame which they contribute to lack of investment in cycling infrastructure and bicycle helmet legislation. However, Olivier et al (2012) argue any analysis over such a long-time frame should account for the ageing Australian population. Using age/sex rates standardised to the 2011 Australian population, Olivier et al (2012) estimated an 8% increase in cycling exposure over this time frame.

Australian Summary

Relevant studies were identified assessing BHL in Victoria, New South Wales, Western Australia, South Australia, and the Northern Territory. No individual studies with cycling data were found for the Australian Capital Territory or Tasmania, although travel to work data covers all states/territories and no post-legislation reductions were observed for these jurisdictions. Other Australian-wide studies also do not support the hypothesis BHL deters cycling.

A report was found for Queensland which reported evidence of reduced cycling following BHL (King & Fraine, 1994). However, the data presented are counts of non-head injuries and not counts of cyclists. Since head injured cyclists are more likely to be admitted to hospital, it is possible the observed reductions in non-head injuries are due to increases in helmet wearing. This study has been excluded since it is not possible to identify counts of cyclists or a valid control group from the reported data.

There is some evidence of reduced cycling for teenagers cycling to school in Victoria, New South Wales and the Northern Territory; however, similar reductions were not found for primary school children in Victoria or the Northern Territory. Although there were observed reductions in WA children cycling to school, the downward trend began at least three years prior to legislation. There were increases in the counts of adult cyclists in Victoria and New South Wales. In Perth, there were increases in commuters but a decrease in recreational cyclist counts while WA police reported crashes involving a cyclist was in a steady decline prior to legislation.

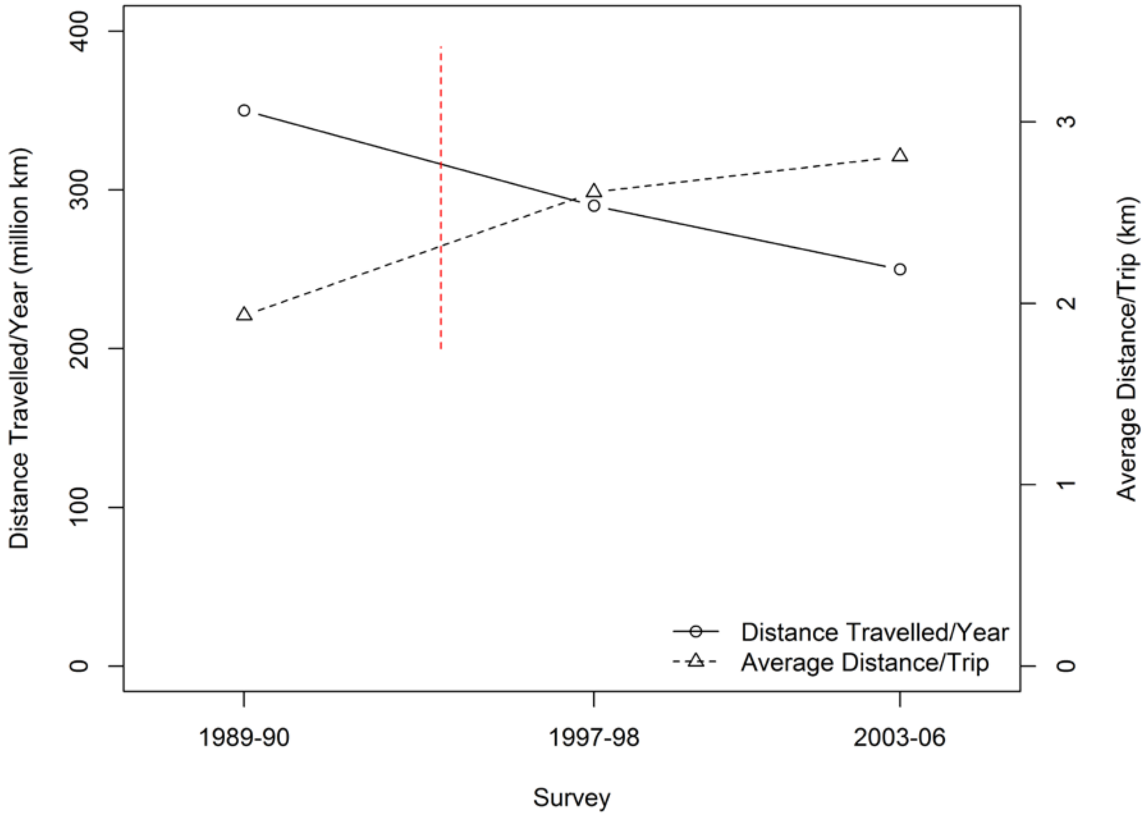
Stratified random sampling surveys in South Australia and Western Australia found no change in cycling frequency following legislation. Additionally, there was no observable reduction in Adelaide commuter cyclists.

When taken as a whole, there is no consistent evidence BHL deters cycling in Australia.

3.3.2. Cycling in New Zealand

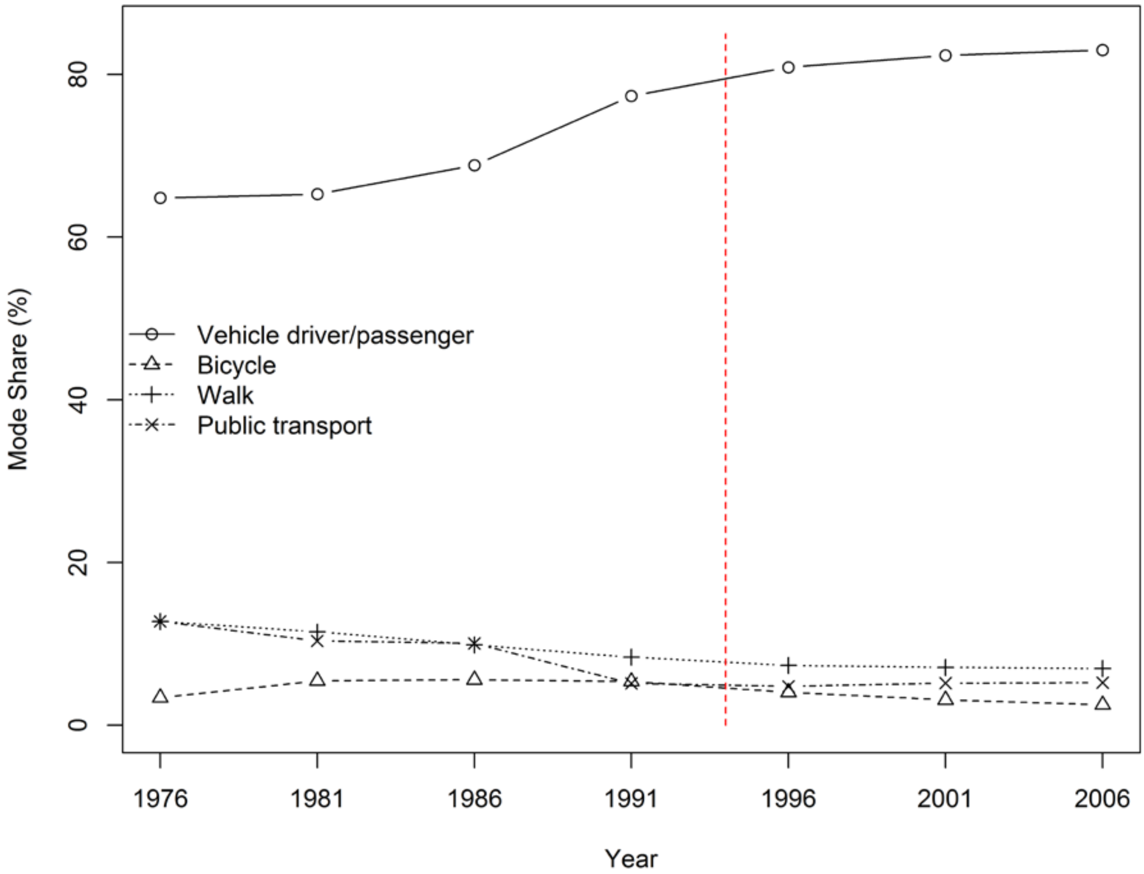
Bicycle helmet legislation was introduced on 1 January 1994 in New Zealand for cyclists of all ages (Povey et al, 1999). Land Transport New Zealand (2007) reported on measures of cycling exposure including millions of kilometres travelled by bicycle, hours spent cycling and the number of trips for three surveys conducted in 1989-90, 1997-98, and 2003-06. Summary data for distance travelled by bicycle and average length of trips is given in Figure 3.18. There were reductions across all surveys in the numbers of trips, hours spent cycling, and distance travelled by bicycle. However, the average trip length increased during this time. These results suggest fewer trips over a short distance and potentially a reduction in certain types of cycling. However, caution should be exercised in overinterpreting these results with regards to BHL as there is a six-year gap (1991-1996) centred at the helmet law date without any exposure data and existing trends cannot be estimated from only one pre-legislation observation.

Figure 3.18. Occurrence of cycling and walking (source: Land Transport New Zealand, 2007)



Tin Tin et al (2009) report data on the main means of work travel that is collected as part of the New Zealand census from 1976 to 2006. This data is self-reported for workers 15 years and older and is collected every five years on a single day. From 1991, surveys were conducted on the first Tuesday in March and prior surveys were not conducted on a fixed date. The results exclude those who did not travel to work that day. The data from these surveys is given in Figure 3.19.

Figure 3.19. Main means of travel to work in New Zealand (source: Tin Tin et al, 2009)

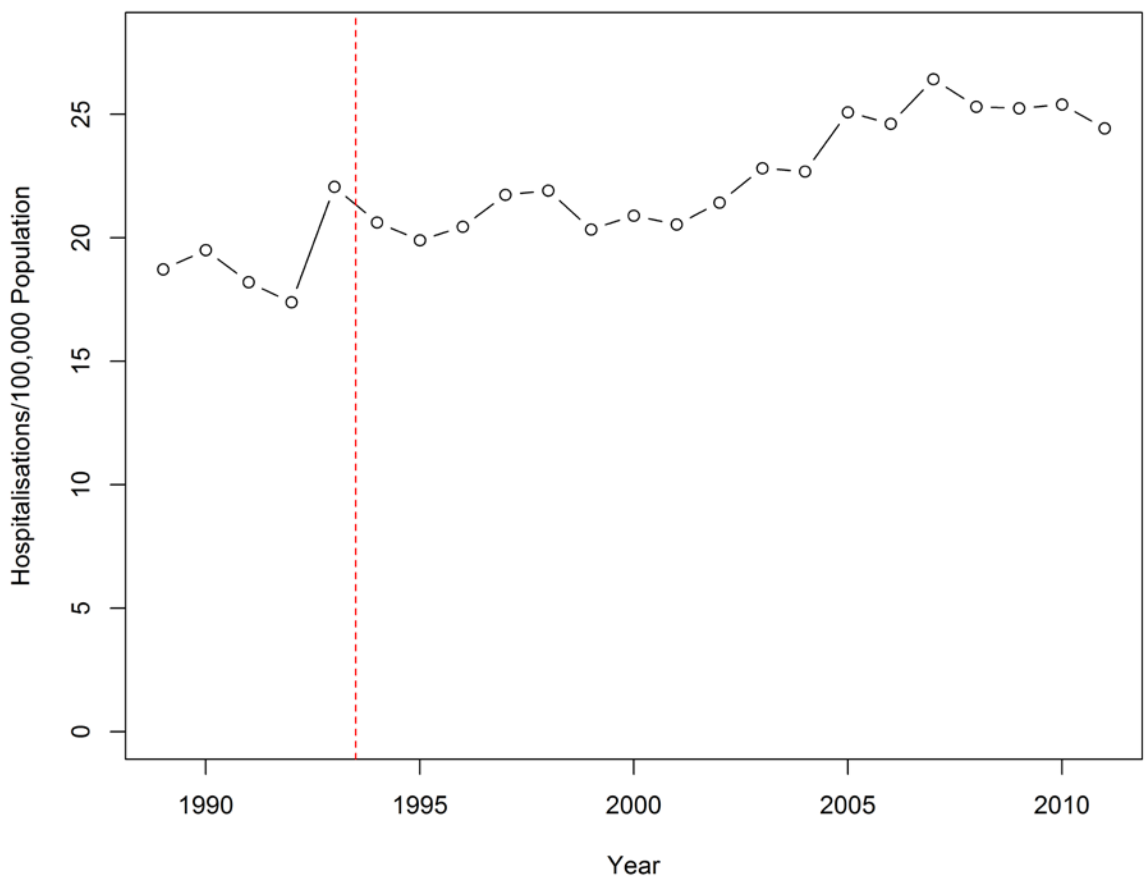


Estimates of cycling mode share has declined in New Zealand following BHL. This may be interpreted as deterrent effects of legislation; however, other active transport modes (walking, public transportation) also declined during this period while motorised transport increased and cycling as the main mode to work peaked in 1986, eight years prior to helmet legislation.

The study authors found cycling to work was negatively correlated with distance to work and positively correlated with average sunshine hours. Regions with large travel distances (>10km) had low rates of cycling with 89% of those cycling to work living in regions with an average travel distance less than 10km. During the study period, Wellington and Nelson invested in active transport and each city observed increases in walking mode share. Further, Tin Tin et al (2009) attribute the decline in active transport modes to "under-investment in public transport and cycling and walking infrastructure". Mode share estimates taken on single days also do not allow estimation of daily/weekly/monthly variability and it is unclear if the observed reductions are due to natural variability or a general shift from active transport to personal vehicles.

Similar to Western Australia, New Zealand has electronic hospitalisation records with several years of data prior to BHL. Hospital records in New Zealand are coded using ICD-9-CM and injuries to the head, face and neck were identified using the codes in Table 3.3. The yearly rate of cyclists presenting without injuries to the head, face or neck is given in Figure 3.20. Following helmet legislation, there is no discernible reduction in hospitalisation rates for the control time series.

Figure 3.20. Rate of bicycle-related hospitalisations without a head, face or neck injury in New Zealand from 1989-2011 (source: New Zealand Ministry of Health)



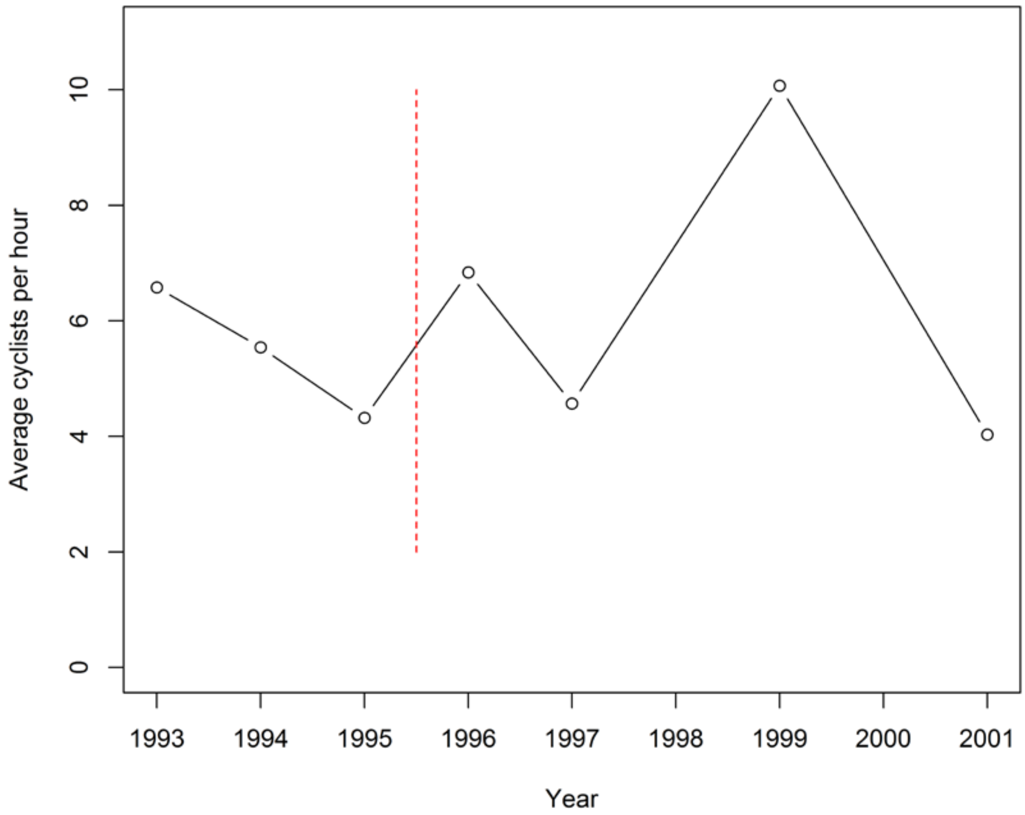
3.3.3. Cycling in Canada

Ontario was the first Canadian province to introduce bicycle helmet legislation on October 1995 for children. Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland and Labrador, Nova Scotia, and Prince Edward Island introduced similar legislation by April 2015. With the exception of Alberta, Manitoba and Ontario, these laws apply to cyclists of all ages.

Ontario

Bicycle helmet legislation was introduced in Ontario on 1 October 1995 for cyclists under 18 years of age. A series of surveys on helmet use were conducted in East York, Ontario from 1993 to 2001 (Macpherson et al, 2001; Macpherson et al, 2006). Child cyclists were observed at 111 sites (schools, parks, residential streets, and major intersections) for years 1993–97, 1999 and 2001. The average number of child cyclists observed per hour are given in Figure 3.21. This study found a decreasing trend in cycling rates prior to legislation which was followed by an increase in cycling after legislation. The 1999 survey, four years post-legislation, observed the largest rate of cycling among the surveys.

Figure 3.21. Average child cyclists observed per hour in East York, Ontario from 1993-2001 (source: Macpherson et al, 2001; Macpherson et al, 2006)



Alberta

Bicycle helmet legislation was introduced in Alberta on May 2002 for children under 18 years of age. Two studies have assessed the impact of BHL on cycling in Alberta (Dennis et al, 2010; Karkhaneh, 2011).

Dennis et al (2010) extracted cycling data from the Canadian Community Health Survey for years 2000-01, 2003, 2005, and 2007. These surveys asked responders whether they had cycled in the past three months, how many times they had cycled in the past three months, and cycling commuters were asked how many hours they spent cycling for work, school or errands within the past week.

Bicycle helmet legislation was introduced in Alberta and Prince Edward Island (PEI) such that the survey data included both pre- and post-legislation observations. The prevalence of recreational cycling for Alberta, Prince Edward Island and other provinces is given in Figure 3.22 and a similar plot for commuter cycling is given in Figure 3.23. With regards to cycling in Alberta, recreational and commuter cycling prevalence among youth increased following helmet legislation. An increase was also evident among Alberta adults during this time.

Figure 3.22. Prevalence of recreational cycling in Alberta, Prince Edward Island and other Canadian provinces by age group for years 2001-2007 (source: Dennis et al, 2010)

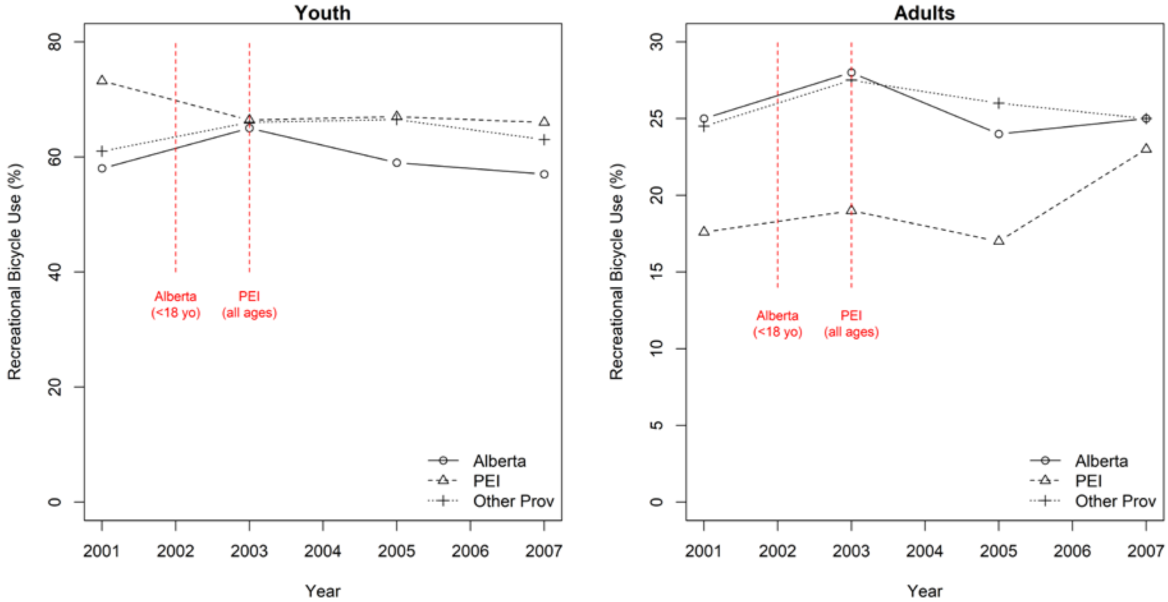
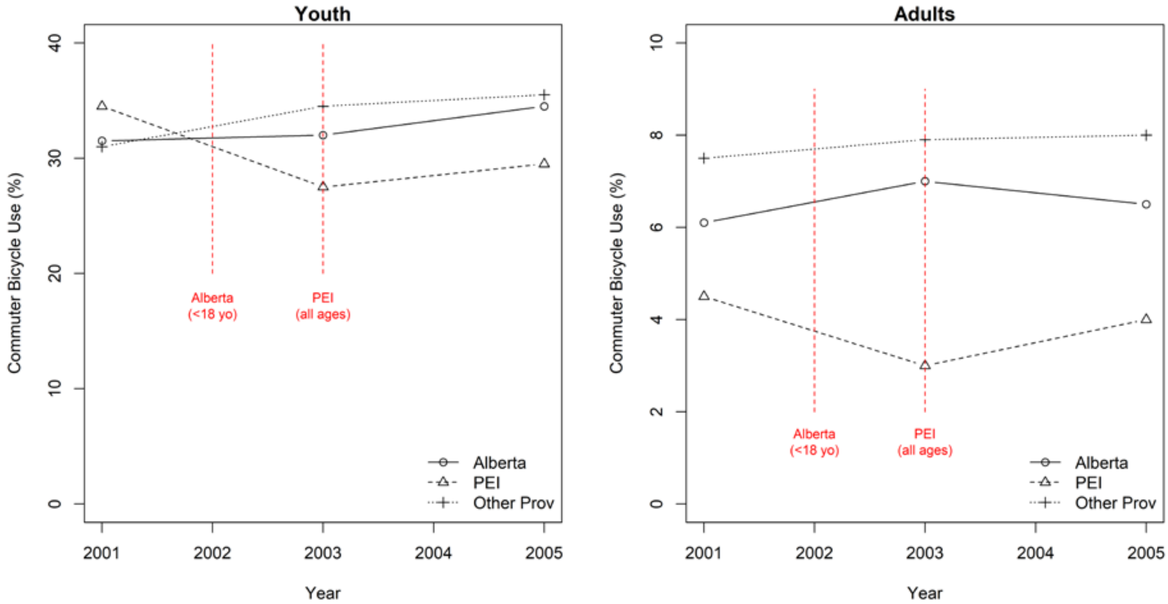


Figure 3.23. Prevalence of commuter cycling in Alberta, Prince Edward Island and other Canadian provinces by age group for years 2001-2007 (source: Dennis et al, 2010)



Karkhaneh (2011) conducted direct observation surveys in Alberta at 270 randomly selected sites from June to September for years 2000 and 2006. The six types of locations were schools, universities/colleges, parks, commuter routes, designated cycling paths and residential areas.

Among children (<13 years), there were observed reductions in cycling to school and on commuter routes, while there was an increase in cycling on campus and non-significant changes in cycling in parks and cycling paths. There was an observed reduction for children in residential areas which was significant at the 10% level. For adolescents (13-18 years), there were also reductions for cycling to school and on commuter routes, while there were no changes in cycling on campus, in parks, on cycling paths or residential areas. Although not subject to helmet legislation, there was an increase in adults cycling to school and on commuter routes, while there were non-significant changes for those cycling on campus, in parks, on cycling paths, and in residential areas.

Prince Edward Island

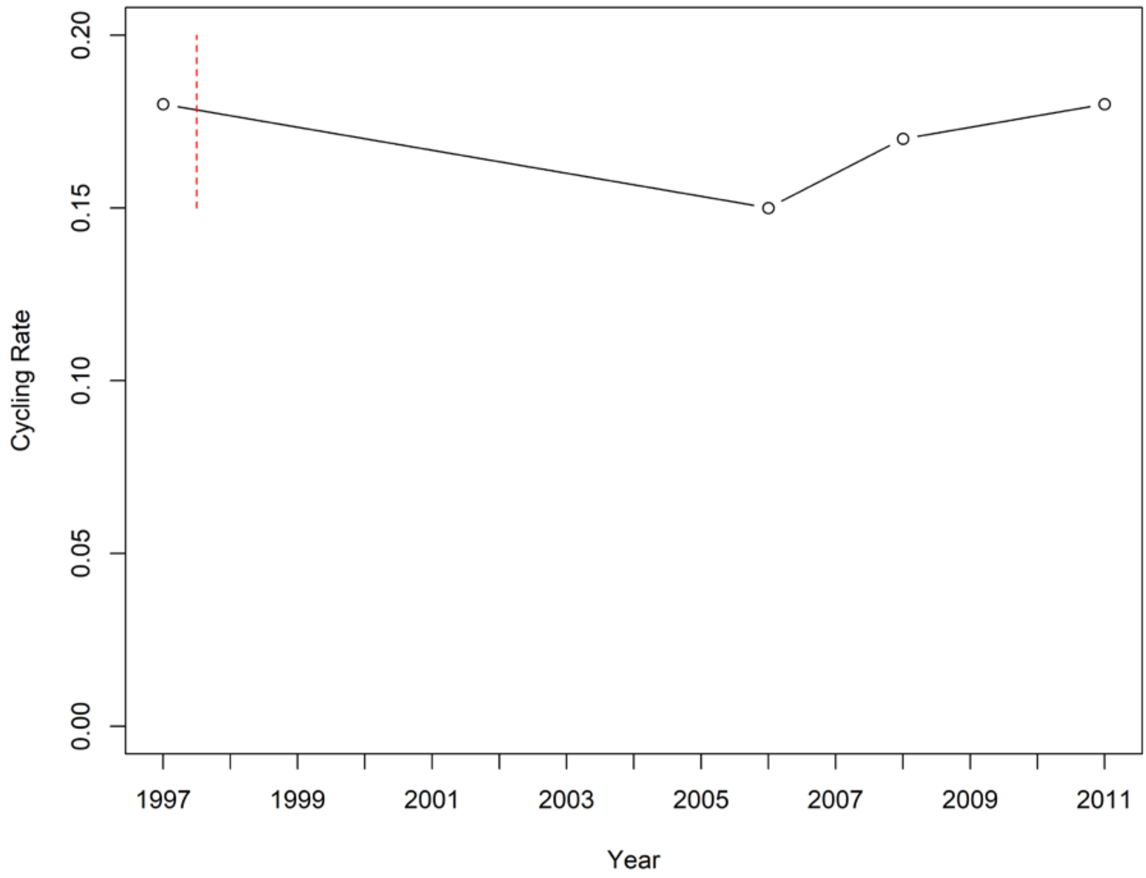
Bicycle helmet legislation was introduced in Prince Edward Island on July 2003 for cyclists of all ages. As discussed above, Dennis et al (2010) reported cycling data for PEI from the Canadian Community Health Survey. Note that the 2003 survey includes responses that are both pre- and post-legislation since the law was introduced mid-year. Neither recreational nor commuter cycling changed significantly following legislation in PEI.

Nova Scotia

Bicycle helmet legislation was introduced in Nova Scotia in July 1997 for cyclists of all ages (Huybers et al, 2017). There was no enforcement for the first two months of legislation and non-compliance attracted a $25 fine from September 1997. Operation Headway-Noggin' Knowledge began in 2004 and was also run for years 2006-20007 to improve helmet wearing. This program allowed non-compliers to sit a 2-hour education program in lieu of a fine and court costs.

Direct observation surveys were conducted in Halifax prior to helmet legislation and again 9, 11 and 14 years post-legislation. The cycling rate, computed as the number of observed cyclists divided by the Halifax population, is presented in Figure 3.24. The authors found BHL was not associated with reductions cycling.

Figure 3.24. Rate of cycling in Halifax for years 1997-2011 (source: Huybers et al, 2017)



3.3.4. Cycling in the United States

There have been 225 bicycle helmet laws enacted in the United States and only two studies were identified examining the effect of such laws on bicycle use (Carpenter & Stehr, 2011; Kraemer, 2016). Both studies make use of large scale health surveys that include questions regarding bicycle use for children.

Carpenter and Stehr (2011) extracted data from the Behavioral Risk Factor Surveillance System (BRFSS) for 1995-2000 and Youth Risk Behavior Surveillance System (YRBSS) for 1991-2005. These surveys identify participants by random-digital-dialing of households in which parents were asked whether their oldest child (under 16 years) never rides a bicycle. The effect of bicycle helmet legislation on bicycle riding was assessed by comparing within-state changes for youths in states adopting or not adopting BHL in the same year.

The authors used least square regression to examine the effect of bicycle helmet legislation on cycling. However, least square regression is not an appropriate method to analyse the effect of a variable on a binary outcome (i.e., whether cycling or not) and their fit to the data is questionable (R^2=0.087 and R^2=0.074). The authors report reductions in the probability of youths riding a bicycle by 3-5% for jurisdictions with helmet legislation. The authors also found helmet legislation was associated with a 19% reduction in youth bicycle fatalities and increased helmet use by 20-34%.

Kraemer (2016) also used the Youth Risk Behavior Survey (YRBS) data to compare jurisdictions with helmet legislation (Dallas, Florida counties, San Diego) against a control (Chicago). Bicycle use was measured dichotomously as whether the respondent had ridden a bicycle in the past 12 months. Changes in cycling before and after legislation was examined with multiple methods of causal identification.

The author reported a non-significant increase in cycling in Dallas (2.8%) relative to the control group. There was also a non-significant increase in cycling in Florida counties (1.7%) relative to an age-based control, and a marginally significant (5.5%) reduction compared to Chicago controls during the mandate-only phase and a significant (5.5%) reduction after the penalty's incorporation.

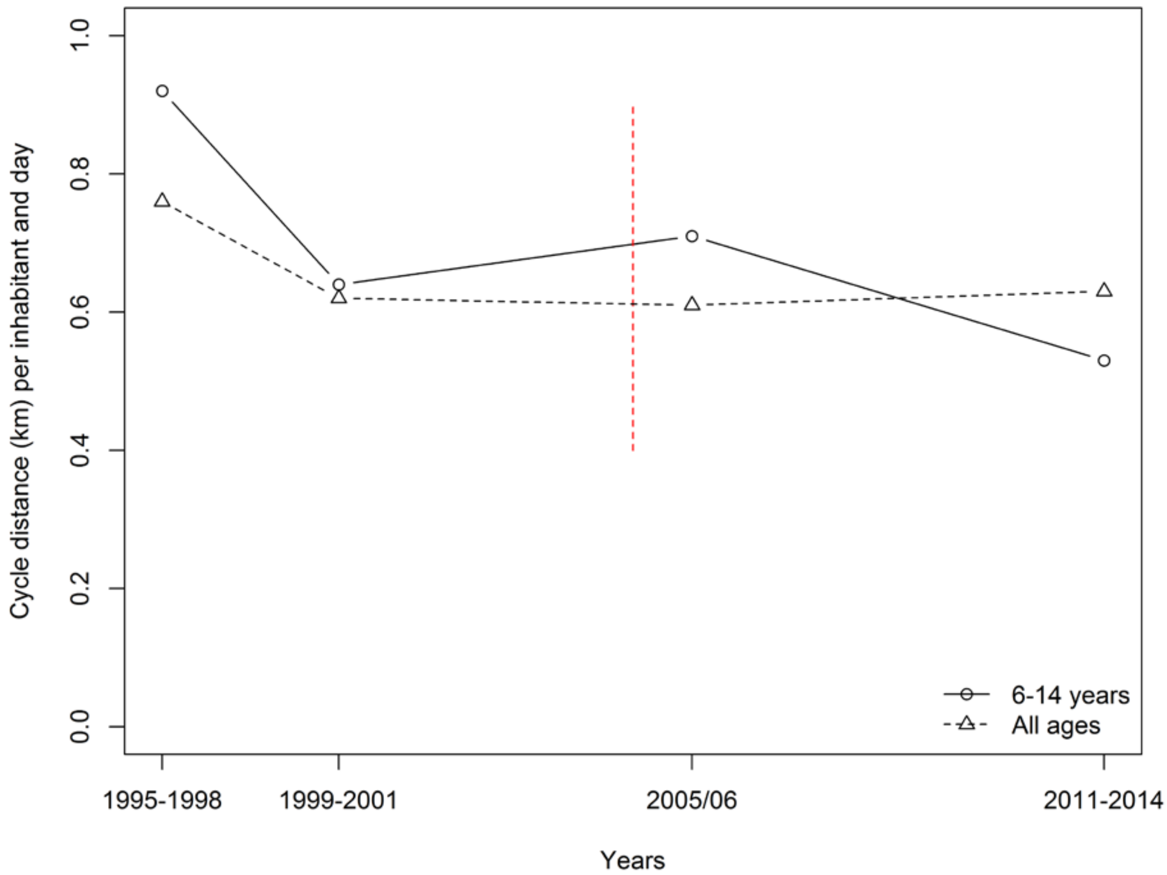
3.3.5. Cycling in European Countries

The literature search identified three European studies with data collected in Sweden, Spain and Finland (Petersen et al, 2015; Molina-García & Queralt, 2016; Radun & Olivier, 2018). Bicycle helmet use was introduced in Sweden in January 2005 for children up to 15 years of age. A fine can be given for noncompliance; however, the fine is given to the parent and not the child.

Petersen and colleagues (2015) reported summary data from Swedish national travel surveys for those aged 8-64 years conducted for years 1995-1998, 1999-2001, 2005/06 and 2011-2014. Cycling was measured as kilometres travelled and number of trips by bike.

The total distance travelled by bicycle for all ages did not change following helmet legislation in 2005. For those aged 6-14 years, the cycling distance per inhabitant per day decreased by 42% from the first to last surveys (see Figure 3.25). However, the largest reductions in cycling occurred from the first to second surveys when helmet legislation was not in effect and there was an increase from the surveys immediately prior and following helmet legislation. There were reductions in cycling for those aged 15-44 between these surveys, although the helmet law did not apply to that age range.

Figure 3.25. Cycle distance (km) per inhabitant and day for children (6-14 years) and all-ages (6+ years) in Sweden (source: Petersen et al, 2015)



Bicycle helmet legislation was first introduced in 2004 for cycling between cities in Spain. This law was modified in May 2014 to also apply to children under 16 years of age in all areas. Molina-Garcia and Queralt (2016) conducted a self-report survey of cycling-to-school behaviour on 262 students (12-16 years old) at a single school in Valencia, Spain. The data collection was conducted in two rounds including April 2014 (1 month before the introduction of BHL) and November 2014 (6 months after the introduction of BHL). Descriptive statistics for cycling to school pre- and post-legislation are given in Table 3.6. The authors found no significant mean changes in cycling to school after the introduction of bicycle helmet legislation.

Table 3.6. Descriptive statistics on cycling to school and helmet use for April and November 2014 (source: Molina-García & Queralt, 2016)

	Mean (SD) Trips/Week	
	Apr 2014	**Nov 2014**
All	7.3 (3.4)	7.3 (3.8)
Gender		
Boys	6.9 (3.6)	6.9 (4.1)
Girls	9.3 (1.2)	9.3 (1.2)
Age (yrs)		
12-13	8.4 (3.6)	8.0 (4.5)
14-16	6.8 (3.4)	7.0 (3.7)

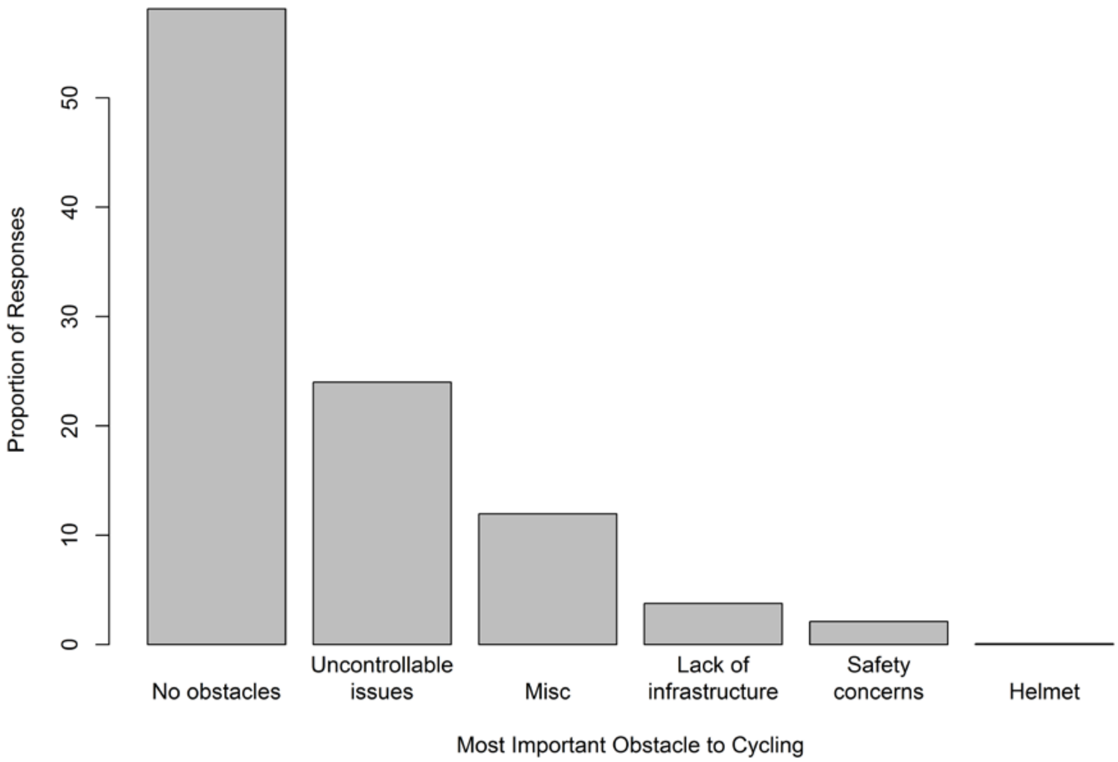
Bicycle helmet legislation was introduced in Finland for cyclists of all-ages in January 2003. There are no fines associated with non-compliance. There has been an ongoing discussion in Finland regarding their helmet law including a formal proposal to repeal in February 2017 (Finnish Government, 2017 (a)). This proposal was motivated by concerns regarding future bicycle-share schemes and the suggested deterring effect of BHL on cycling. However, the Finnish government have dropped bicycle helmets from future discussions of potential changes to their road traffic laws (Finnish Government, 2017 (b)).

Cycling exposure data was collected in Finland as part of the 1998/1999, 2004/2005, and 2010/2011 National Travel Surveys (Radun & Olivier, 2018). Cycling in Finland declined from the first to third surveys by 21% in kilometres travelled and by 23% in numbers of trips. However, it is unclear whether the ageing Finnish population is related to the decline.

Although there were measurable declines in cycling in Finland corresponding to the introduction of BHL, there is evidence it was unlikely BHL was a major cause. The 2004/2005 National Travel Survey included a question regarding a person's most important obstacle to cycling. Out of 13,286 responses, helmet use was selected by nine responders (0.063%). The distribution of the responses is given in Figure 3.26 which indicates lack of infrastructure and safety concerns are much more common responses.

Note that responses were combined for "uncontrollable issues" (long distances, poor weather, old age, illness, injury, disability, cycling is slow), "miscellaneous" (no bicycle, bicycle broken, need to transport things, exercise makes you hot, laziness, self-comfort, other), "lack of infrastructure" (bicycle parking, lack of cycling paths/lanes, road crossings, signage for walking/cycling), and "concerns for safety" (risk of injury, lack of safety, bicycle theft).

Figure 3.26. Proportions of responses for most important obstacle to cycling for 2004/2005 Finnish population (6+ years of age) (source: Radun & Olivier, 2018)



3.4. Discussion

This systematic review aimed to assess whether introducing bicycle helmet legislation is associated with reductions in cycling. The search identified 35 relevant journal articles, technical reports or data sets from 18 jurisdictions in 7 countries. Some studies are part of a series of studies and, when combined, constitute 23 collections of studies. Brief summaries are given in Table 3.7. Although the number of studies in this review is much larger than the six identified in the Cochrane review with none measuring cycling participation rates (Macpherson & Spinks, 2008), the search identified no relevant data for twenty-one countries with bicycle helmet legislation.

Most studies included in this review do not support the hypothesis bicycle helmet legislation reduces cycling. This includes thirteen studies that do not support the hypothesis, eight studies with mixed results (i.e., evidence for and against), and two supportive studies. The two studies with data supportive of the hypothesis are from New Zealand (Tin Tin et al, 2009) and the USA (Carpenter & Stehr, 2011). Other studies from these countries are at best mixed with regards to their support of the helmet law deterrent hypothesis (Land Transport New Zealand, 2007; NZ Ministry of Health; Kraemer, 2016), so on balance it is unlikely there were any consistent cycling reductions across demographic groups in these countries following BHL.

There were several instances of fewer children observed cycling to school following helmet legislation. This included teens in Victoria, Western Australia, the Northern Territory and Alberta. However, this phenomenon was not observed for primary school children in Victoria or the Northern Territory. Additionally, there was an existing downward trend in the proportions of primary and secondary children cycling to school in Western Australia, and the reduction in NSW children cycling to school corresponded to an existing increase in children being driven to school. A later Spanish study found no reductions in cycling to school following their recently modified law that applies to children in all areas. In New Zealand, there were campaigns to discourage children less than 9 years of age to cycle to school (Moyes, 2007), which may account for fewer observed children cycling to school but not less cycling overall.

Most of the included studies originated from Australia which enacted helmet legislation over 25 years ago and most other laws are at least 10 years old. It is, therefore, important to discuss contemporary views of helmet legislation in jurisdictions with and without helmet legislation.

A 2012 Australian report estimates 94% of Australians favour bicycle helmet legislation (Essential Vision, 2012), only one responder to a 2015 ACT survey (n=407 responders) indicated helmet use was a reason for not riding a bicycle (ACT, 2015) and less than 1% of responders (n=400) in a follow-up survey (ACT, 2017), and 3% of non-cycling Victorians stated helmet legislation was a barrier (Amy Gillett Foundation, 2015). Two surveys from the

National Heart Foundation of Australia identified helmet use as the 10th and 13th most cited barrier to cycling for cyclists and non-cyclists respectively (National Heart Foundation, 2011) and 4.1% of women indicated not having to wear helmets as the main reason they could be encouraged to cycle more (National Heart Foundation, 2013). For these surveys, the lack of cycling infrastructure and safety concerns were the most common responses. Rissel and Wen (2011) estimate 22.6% of Australians would cycle more without BHL; however, the survey asked only helmet-related questions, so it is unclear if responders would still be deterred by more commonly accepted reasons such as lack of cycling infrastructure.

There have been similar surveys in countries without universal helmet legislation with similar results. A 2012 UK survey found 79% of Britons favour BHL with 15% opposed (YouGov, 2012), a US survey found 67% support BHL (YouGov, 2013), and a 2017 Danish survey found 72% support helmet legislation for children and 49% favour legislation for all-ages (Pettersen, 2017).

The results of this systematic review do not justify complacency with regards to bicycle helmet legislation and cycling safety. The available evidence does indicate helmet use will mitigate cycling head injury in a fall or crash, bicycle helmet legislation will increase helmet wearing rates, and such legislation is associated with reductions in cycling head injury. However, crash avoidance strategies such as infrastructure that separates cyclists from motorised traffic can further reduce cycling injury (Olivier, Walter & Grzebieta, 2013). Dedicated cycling infrastructure also makes cycling more attractive to non-cyclists. Crash avoidance strategies alone are also an incomplete approach to cycling safety as injuries from single vehicle crashes are the most common in hospital data and increasing among cycling fatalities (Boufous & Olivier, 2016; Schepers et al, 2017).

Bicycle helmet design could also be improved. Although current helmet technology is associated with an approximate 70% and 65% reduction in serious and fatal head injury respectively, there is clearly room for improvement. One mechanism recently discussed was to harmonise the various bicycle helmet standards and to create star rating scheme in an effort to impel manufacturers to improve helmet technology (ICSC, 2017) similar to the SAFER rating system for motorcycle helmets (CRASH, 2017). The Hovding airbag helmet has also been proposed to improve both comfort and safety (Stigson et al, 2017; Kurt et al, 2017).

Table 3.7. Characteristics of studies meeting selection criteria

Jurisdiction	Author & Year	Study Design	Summary of Results	Supports Hypothesis*
Victoria (Australia)	Cameron et al, 1992; Finch et al, 1993; Cameron et al, 1994 (a); Cameron et al, 1994 (b)	Direct observation at fixed locations	Counts from helmet use surveys indicate very little change in cycling for young children, a 36% reduction in cycling by teenagers, a 44% increase in adults cycling, and an increase in cycling overall.	✗✓
South Australia	Marshall & White, 1994	Self-report survey using stratified random sampling	Very little change in the self-reported frequency of bicycle riding between 1990 and 1993 regardless of age or gender.	✗
Western Australia	Healy & Maisey, 1992; Heathcote, 1993; Maisey, 1993	Direct observation at fixed locations	The proportion of children cycling to/from school declined slightly, but the reduction was part of an existing downward trend. Counts of commuter cyclists increased while recreational cyclists decreased. There was a reduction in police-reported crashes, but this was part of an existing downward trend. The count of cyclists crossing two bridges in Perth declined.	✗✓
	Heathcote & Maisey, 1994	Telephone survey using stratified random sampling	Frequency of cycling was similar from 1989 to 1993 (48% vs 51% cycled in the past year).	✗
	Laolert, 2014	Crash data: Department of Health WA	Rate of cycling hospitalisations without a head, face or neck injury in WA has steadily increased over a forty-year period with no sustained reduction following BHL.	✗
New South Wales (Australia)	Walker, 1990; Walker 1991; Walker, 1992; Smith & Milthorpe, 1993; Smith & Milthorpe, 1994	Direct observation at fixed locations over four years (1990-1993)	An increase in adult cycling at road intersections from 1990 to 1991 and a decline in children cycling from 1991 to 1992. Primary cycling routes (cycleways, cycle parks and main arterial roads) were not surveyed following legislation. On a per-site basis, very few locations exhibit sustained declines following legislation.	✗✓
	Walter et al, 2011	Crash data: NSW Admitted Patients Data Collection	Arm and leg injuries were used as a quasi-induced measure of exposure; Limb injuries were similar pre- to post-legislation.	✗
Northern Territory (Australia)	van Zyl, 1993	Direct observations at fixed locations	No change in the number of primary school cyclists; A 64% decline in the number of secondary school cyclists; Data was collected for commuter cyclists, but counts were not provided.	✗✓
Australia	ABS, 2013	Self-report survey using census data	Following BHL, number of cycling to work increased for ACT, NSW, QLD and TAS, decreased for NT and WA, and were similar for SA and VIC. Cycling mode share increased from 1986 to 1991.	✗✓

Jurisdiction	Author & Year	Study Design	Summary of Results	Supports Hypothesis*
	Cosgrove, 2011	Multiple methods using multiple sources	Kilometres of cycling in metropolitan areas reached its peak around World War II and steadily declined thereafter. Other active transport modes also declined during this time.	✗
	Gillham & Rissel, 2012; Olivier et al, 2012	Survey; Telephone survey	Accounting for the aging Australian population, cycling increased by 8% from the first survey (1985/86) to the second survey (2011).	✗
New Zealand	Land Transport New Zealand, 2007	Household travel survey; Changes in hours of cycling are compared to changes in walking	From 1989-1990 to 2003-2006, the number of cycling trips and total distance cycled decreased. However, the duration and distance of average cycling increased. Cycling declined to about 2.4% of main means of travel to work. Due to no data in a 6-year window centred around the introduction of BHL in January 1994, it is not possible to identify any existing trends or changes in cycling/walking near the introduction of helmet legislation.	✗✓
New Zealand	Tin Tin et al, 2009	Self-report survey (census data collected every 5 years) in a 15-year period (1991-2006)	Cycling prevalence declined with age. The number of people cycling to work declined from 1991 to 2006. Due to data collected on single days 5 years apart, it is difficult to identify existing trends or account for daily/weekly/monthly variability in cycling. There is evidence of declines across all active transport modes indicating a shift to private vehicle travel.	✓
New Zealand	New Zealand Ministry of Health	Crash data: electronic hospitalisation records	There is no discernible reduction in hospitalisation rates for cyclists with no head, face or neck injuries following BHL.	✗
Ontario (Canada)	Macpherson et al, 2001; Macpherson et al, 2006; Macpherson et al, 2012 (correction of 2006 study)	Direct observation (1993-1997, 1999 and 2001) at fixed locations	Average observed cyclists per hour was higher in 1997 compared to 1995. However, the increase was not sustained over time. Overall, no change in average cycling level was found.	✗
PEI & Alberta (Canada)	Dennis et al, 2010	Phone/in person interview survey	No evidence of sustained changes in recreational or commuter bicycle use.	✗
Alberta (Canada)	Karkhaneh, 2011	Direct observation at fixed locations	Counts of cyclists declined for some groups (cycling to/from school & on commuter roads for children and adolescents) but other groups were similar or increased (cycling on commuter roads in adults & cycling in campus areas in children) from pre- to post-legislation.	✗✓
Nova Scotia (Canada)	Huybers et al, 2017	Direct observation at fixed locations	Percentages of cycling in 2006, 2008, and 2011 were similar to the pre-legislation percentage in 1997.	✗

Jurisdiction	Author & Year	Study Design	Summary of Results	Supports Hypothesis*
U.S.	Carpenter & Stehr, 2011	Random-digital-dialing telephone survey	Helmet laws associated with 3-5% less youth cycling. Methods and model fit were questionable.	✓
Dallas TX, San Diego CA, Southern Florida (U.S.)	Kraemer, 2016	Self-report survey; two-stage cluster sampling	Non-significant increase in cycling in Dallas and Florida counties. Marginally significant reduction in Florida counties, compared to Chicago. Significant reduction after the penalty's incorporation.	✗✓
Sweden	Petersen et al, 2015	Interviews with residents	A decline in average travel distance and number of trips for 1995 vs 2014. However, cycling increased from 1999-2001 2005/2006 surveys for children affected by legislation (6-14 years).	✗
Valencia (Spain)	Molina-García & Queralt, 2016	Self-report survey	No significant changes in average weekly cycling trips to school was found following helmet legislation.	✗
Finland	National Travel Surveys	National Travel Surveys	From 1998/1999 to 2010/2011, cycling kilometres travelled had declined by 21% and number of cycling trips had declined by 23%. However, only 0.063% of responders indicated helmet use was their primary barrier to cycling the year after legislation.	✗

* Hypothesis tested: Bicycle helmet legislation deters cycling

Key: ✓ (supportive evidence), ✗ (not supportive evidence), ✗✓ (mixed evidence)

3.5. Limitations

There are limitations to the studies included in this systematic review and the review itself. Many of the included studies use either direct observational surveys in fixed locations or random sampling surveys. None of these designs are perfect, as they are subject to biases associated with such studies. In direct observation surveys, participants or locations are not randomly selected; therefore, they are not likely to be representative of the population. The data from these surveys can also not provide population estimates of cycling exposure. Random sampling surveys are more likely to be representative of the population; however, they are subject to recall bias as individuals might not be able to accurately report past events.

Ride to work data, such as in Australia and New Zealand, also have methodological shortcomings. Although this data is a census, it corresponds to single-day observations taken five years apart which makes the estimation of trends challenging and the estimation of daily/monthly/yearly variability impossible.

Quasi-induced exposure methods are beneficial since hospital records are routinely collected and data can be aggregated to fit any time unit. However, it is unclear to what extent these methods accurately estimate true cycling exposure.

Although the present study provides some insight into the effect of BHL on bicycling, it does not capture reasons why bicycling may be affected by such laws. Our review identified very few studies on barriers to cycling with regards to bicycle helmet legislation. A Finnish study the year after legislation estimated only 0.06% of the Finnish population believe helmet use is their most important obstacle to cycling. Additionally, recent Australian surveys do not support BHL as a major barrier to cycling among cyclists and non-cyclists.

Although a systematic search was conducted on the literature, it is possible that some studies in the grey literature were not identified. The authors requested data from many sources, but the response rate was low. Language could be a barrier to obtaining relevant information as English is not the primary language for most countries without relevant data. There may also be inaccuracies from non-English language reports.

3.6. Conclusions

Discussions regarding the appropriateness of bicycle helmet legislation are complex and multifaceted. No single study or review can completely support or detract the introduction of such laws. However, with regards to the hypothesis BHL deters cycling, this systematic review failed to identify convincing and consistent evidence to support the hypothesis helmet legislation reduces cycling.

Chapter 4: A Systematic Review on The Effect of Bicycle Helmet Legislation on Risk Compensation

By: Mahsa Esmaelikia, Igor Radun, Raphael Grzebieta, Jake Olivier

4.1. Introduction

An argument against bicycle helmet use is the risk compensation hypothesis, which posits that wearing a helmet leads to riskier behaviour thereby offsetting any safety benefit afforded by the helmet (Adams & Hillman, 2001). To examine the risk compensation hypothesis, previous research has mostly focused on how helmet wearing affects cycling speed (Phillips, Fyhri & Sagberg, 2011; Fyhri, Bjørnskau & Backer-Grøndahl, 2012; Messiah et al, 2012). However, the effect of helmet wearing on actual risk-taking or illegal behaviour has been mostly overlooked in the literature.

There are important aspects that can be deduced from the definition of the risk compensation hypothesis with regards to bicycle helmets. If risk compensation is assumed to be true, the effect is a measurable change in behaviour in a specific direction. If a person changes their usual helmet wearing behaviour, i.e., start or stop wearing a helmet, their level of risk taking would either increase, decrease or stay the same. Risk compensation is only one of six possible scenarios, namely a usual non-helmet wearer puts on a helmet and increases their risk taking. Importantly, evidence in the opposite direction, i.e., taking a helmet off leads to less risky behaviour, is not evidence in support of risk compensation as it is a type of logical fallacy (i.e., affirming the consequent). Note a more inclusive definition is risk homeostasis which could be taken as a change in risky behaviour, increase or decrease, following a change in helmet wearing behaviour.

Change in behaviour following helmet use and the direction of the effect is not always presented in the literature. Some studies have tested and shown that cyclists who usually wear a helmet ride at a slower speed when cycling without a helmet (e.g., Phillips, Fyhri & Sagberg, 2011). Although this finding suggests not wearing helmet leads to less risky behaviour (lower speed), it does not provide any evidence for the opposite direction to support risk compensation (i.e., whether wearing a helmet leads to cycling at a higher speed). Nevertheless, such findings are considered as support for the risk compensation hypothesis in the research literature.

Other studies in the risk compensation literature do not measure changes in behaviour. For example, cross-sectional studies do not include repeated measurements and, therefore, no baseline data is collected to estimate changes in risk-taking or illegal behaviour after wearing a helmet. Some cycling advocates have extended the risk compensation hypothesis to conclude bicycle helmet use should not be promoted or legislated (see, for example, Cyclists' Rights Action Group, 2010).

In another study, the association between wearing a bicycle helmet and the behaviour of motor vehicle drivers was tested. As part of a study to measure motor vehicle overtaking distances for various lane positions for cyclists, Walker (2007) concluded that motorists overtake at significantly closer distances when the cyclist is wearing a helmet than not. A re-analysis of this study (Olivier & Walter, 2013) found the statistical significance from the original study was due to an overpowered study design for detecting a small effect size and the effect vanished when passing distance was categorised by the one-metre rule.

Case-control studies have shed some light on helmet use and cycling behaviour. For example, Bambach et al (2013), in an analysis of linked NSW police and hospital data of cyclists in a motor vehicle collision, found helmet users were less likely to drink alcohol and cycle or to disobey traffic controls. However, helmet users were more likely to cycle in areas with higher posted speeds for motorised traffic and less likely to cycle in a bike lane. Illegal cycling behaviour among non-helmet users was also noted in a Spanish study (Lardelli-Claret et al, 2003) while a New York study found helmet use was negatively associated with alcohol use (Sethi et al, 2016). Additionally, a New South Wales study found proportions of cyclists complying with road rules were similar before and after bicycle helmet legislation when helmet use increased from 25% to 77% for cyclists 16 years or older (Walker, 1991).

There is a lack of consensus in the research literature regarding bicycle helmets and the risk compensation hypothesis, and this gap in knowledge was identified at least 17 years ago (Thompson, Thompson & Rivara, 2001). Therefore, this study aims to shed light on the potential association between bicycle helmet use and risk compensation by systematically reviewing the literature on bicycle helmet wearing and risky behaviour.

4.2. Methods

To address the research question, a systematic review of the peer-reviewed literature was performed on 17 May 2017. In accordance with the study protocol (see Appendix B), the peer-reviewed literature was searched for studies with bicycle helmet content from five research databases (EMBASE, MEDLINE, COMPENDEX, SCOPUS, and WEB OF SCIENCE). The search terms were (bicycl* OR cycl*) AND (helmet*) AND (risk*). In relation to EMBASE, the subject headings for “bicycle”, “helmet”, and “high risk behavior” were used. In relation to MEDLINE, the subject headings for “bicycling”, “head protective devices”, and “risk taking” were used.

The search and removal of duplicate documents were performed independently by two researchers. A title and abstract screen assessment of the articles was performed by the two researchers. Study authors were contacted if relevant data was not reported, but the study met current systematic review inclusion criteria. Study authors were also contacted for a full-text report, when published abstracts met other inclusion criteria. Google Scholar alerts were used to identify relevant articles published after the original search date. The remaining articles were read in full and assessed against inclusion criteria and data was extracted with adherence to the PRISMA statement (Moher et al, 2009). The included studies were independently summarised by two authors (ME & IR) in relation to their sample, study design, and interpretation of results. Conflicts were first discussed by the two reviewers and unresolved disputes were adjudicated by a third author.

In accordance with the protocol, reviewers categorised all articles into four types including commentaries, systematic reviews of previous studies, computer simulations and lab studies, and epidemiological studies (e.g., case-control studies of cycling crash data). To be included in the current systematic review, articles had to provide first instance data. Studies reporting the association between bicycle helmet use and risky behaviour such as disobeying traffic laws were also included.

Commentaries, response letters, and reviews of the literature were included for a full-text review; however, any relevant data were extracted from the source material. Systematic reviews of previous studies were also included for a full-text review to identify relevant source data; however, these reviews were not included in the current systematic review. Relevant computer simulations, lab studies, and epidemiological studies were included for a full-text summary.

In this systematic review, an ideal study would report crash data extracted from the real world using a randomised sample (i.e., cyclists randomised to either wear or not wear a helmet). On the other end of the spectrum, the poorest studies are commentaries, studies that lack a control group, studies that use convenience sampling, and studies that report proxy measures for risk taking.

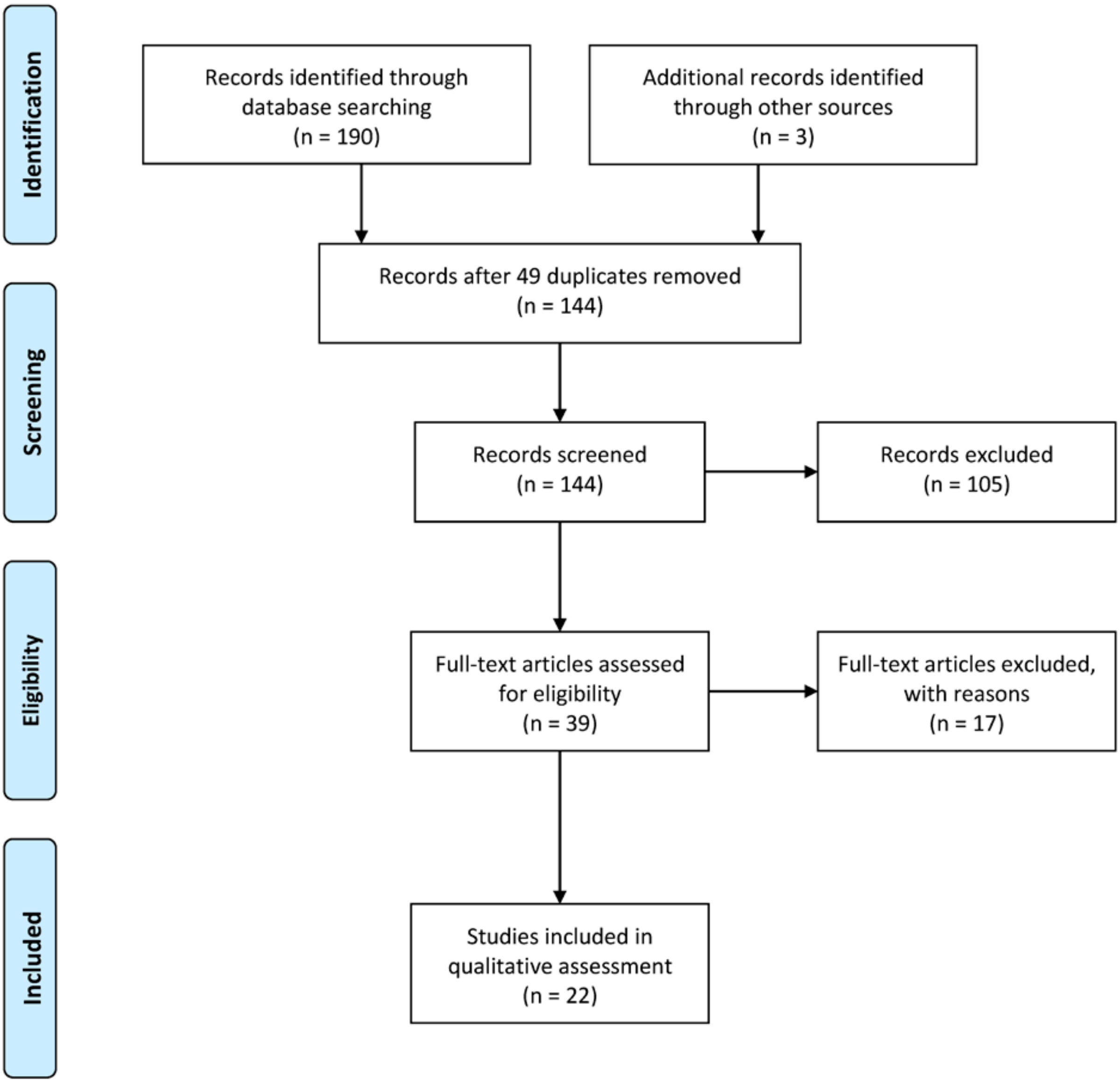
4.3. Results

The flow diagram for reviewed studies is given in Figure 4.1. A search of the peer-reviewed literature resulted in 190 articles, out of which 49 were duplicates and were removed from the list. Three other articles from other sources were also added into the list resulting in 144 records. Authors of an abstract found in the 2015 International Cycling Safety Conference proceedings (Sundfør et al, 2015) were contacted for a full paper; however, the study has not been accepted for publication in a peer-reviewed journal. After screening the titles and abstract, 105 articles were excluded from the study and 39 articles were included for a full-length assessment. Finally, 17 additional studies were excluded leaving 22 eligible studies (See Appendix B for the study protocol). A technical report was identified from other sources (Walker, 1991); however, it was not included for further consideration since it was not peer-reviewed.

The 22 eligible studies were published between 1994 and 2018, five studies were conducted in the United States (Gielen et al, 1994; Klein et al, 2005; Crocker et al, 2012; Webman et al, 2013; Salon & McIntyre, 2018), followed by four studies each in Norway (Phillips et al, 2011; Fyhri et al, 2012; Fyhri et al, 2013; Lajunen, 2016) and in Spain (Lardelli-Claret et al, 2003; Meneses Falcón et al, 2010; Martinez-Ruis et al, 2013; Martinez-Ruis et al, 2014), three studies in Australia (Buckley et al, 2009; Washington et al, 2012; Bambach et al, 2013) , two studies each in the United Kingdom (Walker, 2007; Gamble & Walker, 2016) and in Germany (Orsi et al, 2014; Schleinitz et al, 2017), one study in France (Messiah et al, 2012), and finally one study compared cycling behaviour in Brisbane, Australia and Copenhagen, Denmark (Chataway et al, 2014).

Among the 17 excluded articles, ten studies were commentaries, reviews of the literature or response letters (Adams & Hillman, 2001 (a); Adams & Hillman, 2001 (b) & Adams & Hillman, 2001 (c); Thompson et al, 2001 (a); Thompson et al, 2001 (b); Chapman & Curran, 2004; Newbold, 2012; de Jong, 2012 (b); Hagel et al, 2013; Melo et al, 2014), four studies did not provide any relevant information for the purpose of the current systematic review (Barczyk et al, 2013; Boufous et al, 2012; McCarthy, 1991; Sieg, 2016), two studies did not provide first instance data (de Jong, 2012 (a); Olivier & Terlich, 2016) and one study was not peer-reviewed (Walker, 1991).

Figure 4.1. PRISMA Flowchart for the systematic review of the association between bicycle helmet wearing and risk compensation



4.3.1. Summary of Articles

The twenty-two studies included for a qualitative assessment are summarised below in chronological order of publication. The limitations of each study are also discussed.

Gielen et al (1994)

A self-report survey was conducted on 3,276 school children in three American counties that differed in the strategies they used to promote helmet wearing. Howard County had a bicycle helmet law (<16 years), Montgomery County had an on-going bicycle helmet promotion campaign only, and Baltimore County had neither helmet legislation nor an ongoing promotional campaign. A multivariable analysis (adjusted for grade, sex, ethnicity, and frequency of bicycle riding) showed that risk-taking was not related to helmet use. It also showed that perceived risk of injury was not associated with helmet wearing in Howard County; however, it was negatively associated with helmet wearing in Baltimore and Montgomery counties. The results from this study were mixed regarding risk compensation when it comes to the issue of perceived risk of injury and helmet use. Caution should be exercised when interpreting the results from this study as risk-taking was operationalized as individual's predisposition towards risk taking in general, not specifically in relation to cycling. Therefore, the findings of this study might not be generalisable to the cycling population.

Lardelli-Claret et al (2003)

Data was collected from a cross-section of 22,814 Spanish cyclists involved in an injurious crash from 1990 to 1999 recorded in the Spanish Register of Traffic Crashes with Victims. This study aimed to examine the relationship between committing a traffic violation in a crash and voluntary use of a bicycle helmet. The study period pre-dates a bicycle helmet law introduced in 2000 for travel between cities. The authors found that committing a traffic violation was positively associated with a lower frequency of helmet use (adjusted odds ratio (aOR) = 0.63, 95% confidence interval (CI): 0.58–0.69). Cycling at excessive or dangerous speed, however, was not significantly associated with helmet use either alone (aOR = 0.95, 95% CI: 0.56-1.61) or in combination with any other violation (aOR = 0.97, 95% CI: 0.79-1.20). The use of crash data may be subject to selection bias, as committing an infraction is related to the risk of being involved in a crash. Therefore, the proportion of infractions among the group of cyclists involved in traffic crashes should be higher than for the whole population of cyclists.

Klein et al (2005)

Data was collected on a cross-section of 112,843 multinational school children (11, 13 and 15 years) in the 1997/98 academic year as part of the Human Behavior in School Children (HBSC) study. Students were identified from a cluster sample of n=26 schools. The self-reported survey was used to identify factors that predict bicycle helmet use. The authors found a 31.5% increase on a risk-taking scale (i.e., alcohol and tobacco use, skipping school, and bullying) for cyclists who do not wear helmets. There are important limitations of this study with regards to risk compensation. Risk-taking, operationalized in this study as the risk-taking scale, is a measure of general risk-taking behaviour and not necessarily those relevant to bike riding. Although some jurisdictions in the USA and Canada have bicycle helmet laws, this was not addressed in the analysis. Therefore, this study does not directly address risk compensation and helmet use and the results may not be generalisable to the cycling population.

Walker (2007)

In a naturalistic experimental study, a researcher aimed to examine the association between proximity of overtaking and other factors including helmet wearing. In this study, the author himself was the experimenter riding a bicycle with or without a helmet, while the participants were drivers who overtook him. The author stated that bicycle distance from the road edge was controlled in the analysis. The author found that motor vehicle drivers who overtake cyclists give less space to cyclists who are wearing a helmet, which supports the risk compensation hypothesis.

This study is limited due to potential experimenter effects as the author was the sole bicyclist and the cycling route chosen covered two English cities that were part of the author's route to work. A re-analysis of the data from this study found overtaking distance was similar for close overtaking and differences emerged for distances over 2 metres (Olivier & Walter, 2013). Finally, in this study, wearing a helmet and its effect on a cyclist engaging in risky behaviour were not tested. A critical review of this study can be found elsewhere (Radun & Lajunen, 2018).

Buckley et al (2009)

In an interventional experiment, the authors aimed to examine the effectiveness of a theory-based injury prevention program (Skills for Preventing Injury in Youth, SPIY) on bicycle helmet wearing for 506 year nine students (age 13 to 14 years) from 6 schools in low socioeconomic areas of southwest Queensland, Australia. In this study, two schools were considered as the experimental group (N=268) and 4 other schools served as the comparison group (N=238). The authors found that the intervention was associated with a 20% decrease in self-reported cycling without a helmet in the intervention group; while no change was observed in the comparison group after 6 months. This study also showed that helmet wearing is negatively associated with engaging in other transport-related risks. This study is limited for our purposes as it did not test whether helmet wearing is related to bicycle-related risky behaviour.

Meneses Falcón et al (2010)

In the Madrid and Andalusian regions of Spain, 3,612 secondary students were randomly selected from participating schools. The researchers collected data on risky behaviours related to road safety including bicycle helmet use. The lead author provided cross-tabulations of bicycle helmet wearing and other risky behaviours which were not reported in the article.

In their data set, helmet wearing was more common among those who wear motorcycle helmets (most of the time: 40.0% vs never: 22.6%), who use a seatbelt while in the car with their parents (35.6% vs 6.8%), and who use a seatbelt while in the car with a friend (38.2% vs 12.1%). Helmet wearing was lower among those who have ridden a motorcycle when the driver consumed alcohol (24.4% vs 35.4%), who have driven a motorcycle having consumed alcohol (23.2% vs 34.0%), who crossed the street when they could not (26.6% vs 49.4%), and who like taking risks (24.3% vs 46.4%). Overall, helmet wearing is more common for those reporting safe behaviours and less common for those reporting risky behaviours. However, these results are limited for this review as the self-reported risky behaviours were not related to cycling.

Phillips et al (2011)

In Oslo, a field experimental study recruited 35 cyclists irrespective of whether they usually wear or do not wear a helmet. They then rode a bike for 0.4 km downhill with or without a helmet. In another analysis, participants were dichotomised according to the usual frequency of helmet usage in everyday life. An additional “follow-up” experiment was carried out with 13 participants who rode a bicycle with two hands on the handlebars (“safe condition”) and with one hand on the handlebars (“unsafe condition”).

The authors found that participants who used their own helmet in the experiment cycled more slowly when cycling without a helmet. They also reported increased personal insecurity and perceived risk of accident when cycling without a helmet. However, no difference was shown among those who do not usually wear a helmet. In the follow-up experiment, cyclists reported higher levels of personal insecurity and accident risk, and cycling more slowly when riding in the less safe condition (i.e., with one hand on the handlebars). A limitation of this study is potential observer/experimenter bias due to lack of blinding. Note the authors conclude their study supports the risk compensation hypothesis, although the effect is in the wrong direction (i.e., not wearing a helmet leads to less risky behaviour).

Crocker et al (2012)

The authors assessed the association between alcohol use and helmet wearing in a prospective study of 427 injured cyclists who presented to a regional trauma centre in the United States between December 2006 and April 2009. Data were collected on helmet use, type of helmet, self-reported skill level, alcohol used before or during ride, date and time of the day, severity of head/brain injury, and context of the crash. The authors found that drinking alcohol is positively associated with unsafe cycling practices and risk of injury, and alcohol use is negatively correlated with helmet use.

Fyhri et al (2012)

Data was collected on a cross-section of 1,504 randomly recruited bicycle owners in an insurance register in September 2008. The authors found that traffic violations were negatively related to helmet use and safety equipment use. In addition, being a fast cyclist and perceived risk were positively related to helmet use. The authors concluded that the perceived lack of the effectiveness of bicycle helmet legislation was more likely to be due to a population shift, as opposed to risk compensation mechanisms.

Messiah et al (2012)

This study examined 1,798 cyclists (85% were non-helmet users) who borrowed a bicycle for their own use in a promotional helmet campaign in Bordeaux, France. The authors found the observed speed was higher among helmeted male cyclists (19.2 km/h) than among non-helmeted male cyclists (16.8 km/h, $p < 0.001$); however, the difference was observable for areas of low average speed only and no change was found among females. The authors conclude that if risk compensation exists, then its effects are small.

The data used in this study originated from a naturalistic randomised control trial from the same authors (Constant et al, 2012). However, the randomised groups were not relevant for this secondary analysis. In the original study, one group received only a brochure promoting helmet use, the other only a free helmet, the third group received both the brochure and helmet, while the forth did not receive anything and served as a control group. For the purpose of assessing the risk compensation hypothesis, this study is a prospective cohort study of cyclists who do not usually wear helmets with some of them choosing to wear helmets. Repeated observations for the same cyclist were accounted for using generalised estimating equations; however, cyclists were not observed both wearing and not wearing a helmet and the change in cycling speed is not necessarily in the proper order (i.e., change in speed without and then with a helmet). Therefore, it is unclear whether this study is relevant for risk compensation and bicycle helmets. A critical review of this study can be found elsewhere (Radun et al, 2018).

Washington et al (2012)

A cross-section of 2,500 Queensland children over 17 years old were recruited via advertising, media coverage, posting on cycling forums, distribution of promotional flyers and word of mouth. This study aimed to examine the association between bicycle-related injuries and perceived risk of cycling. The authors found that participants who reported always wearing a helmet were associated with a reduction in crash injury risk and an increase in perceived risk of cycling. A limitation of this study is the non-random selection of participants. Therefore, the results may not be representative of the cycling population.

Bambach et al (2013)

A retrospective case-control study of 6,745 cyclists injured in a motor vehicle collision were identified from linked NSW police and hospital crash data from 2001-2009. This study examined the effect of bicycle helmet use on head injury as well as the association between helmet wearing and bike-related risky behaviours. The authors found that cyclists who did not wear a helmet were more likely to engage in risky behaviour such as disobeying a traffic control and cycling with a blood alcohol concentration greater than 0.05; however, they were less likely to cycle in risky areas such as roads with high speed motorised travel. The primary limitation of this study is a potential selection bias from case-control designs. A follow-up study found similar results using propensity score stratification to lessen the influence of potential allocation bias on synthetic data generated from the published summary statistics (Olivier & Terlich, 2016).

Fyhri et al (2013)

A field experimental study on 27 participants was conducted in Oslo, Norway. Participants were categorised as being a regular helmet wearer (yes or no) and heart-rate variability was used as a measure of psychophysiological load. The participants cycled with one hand in order to increase differences between measures. Each participant was asked to wear their own helmet either in the first or second round of cycling. If they did not arrive with a helmet, they were loaned one. The authors found that cyclists who use a helmet more frequently were more likely to ride faster when wearing a helmet and more likely to ride slower when not wearing a helmet. They also found that participants who normally wear a helmet were more likely to have a higher psychological load when not wearing a helmet, compared to those who are not accustomed to helmet wearing. However, there was no change for participants who do not normally use a helmet. No significant correlation was found between pace and heart rate.

The authors concluded their findings support the risk compensation hypothesis theory; however, the observed effect was in the wrong direction (i.e., regular helmet users rode slower without a helmet). It is not clear whether participants were randomised to treatment (i.e., helmet use), nor whether all participants rode on both sites (cycle path or cycle lane).

Martinez-Ruis et al (2013)

A quasi-induced exposure approach using cross-sectional crash data was used to identify factors related to the risk of causing a road crash that involve cyclists in Spain. The sample was taken from the Spanish Register of Traffic Crashes with Victims and consisted of cyclists who were involved in single (n = 3827) or one-cyclist-one-motor vehicle (n = 19007) injury crashes between 1993-2009. Only crashes in which one party committed an infraction were included in a logistic regression analysis to predict crash responsibility. The authors found that not wearing a helmet was associated with single vehicle crashes and collisions with another vehicle.

Webman et al (2013)

This study was a subset analysis of a 2.5-year prospective cohort study of vulnerable roadway users injured by motor vehicles in New York City. The analysis included injured cyclists (N=374) with known helmet status in crashes with a motor vehicle taken from Bellevue Hospital Center, a level 1 trauma center, between December 2008 and June 2011. This study aimed to evaluate the difference in the demographic information, behaviour, initial hospital evaluation and outcomes of helmeted and non-helmeted cyclists. The authors found that helmet wearing was positively related to riding with the flow of traffic and riding within bike lanes. The authors report no statistical difference in alcohol use between the two groups; however, the observed effect was not inconsequential (OR = 0.53, 95% CI: 0.221.24) and in the direction opposite the risk compensation hypothesis. This study is limited by selection bias due to non-random enrolment of participants and a small sample size.

Chataway et al (2014)

A cross-sectional study compared safety perceptions and bicycle-related behaviour of cyclists in an emerging cycling city (Brisbane, Australia) and an established cycling city (Copenhagen, Denmark). The sample consisted of 894 cyclists from Brisbane and Copenhagen recruited through university networks and cyclist forums (75% of the sample were from Brisbane). Using structural equation modelling, the authors found that using safety gear was positively and negatively associated with the fear of traffic and distracted cycling, respectively. However, given the legislative differences (lights and reflectors are compulsory in both Brisbane and Copenhagen; helmet wearing is only compulsory in Brisbane), that authors acknowledge it is difficult to make comparisons in respect to helmet wearing and safety perceptions. In addition, there may be cultural differences in the use of bicycle helmets in the two cities. To be able to better interpret the findings of this study, the reviewers attempted to obtain separate data for each city, but they were not successful.

Martinez-Ruis et al (2014)

The authors used cross-sectional, crash data from Spain to examine the association of cyclists' age and sex with risk of being involved in a crash with and without adjustment for the amount of exposure. The source data was also used for Martinez-Ruis et al (2013) and

Lardelli-Claret et al (2003). For this study, the data comprised of 17,765 cyclists between 5 and 79 years old involved in one-cyclist-one-motor vehicle injury crashes between 1993 and 2009. The authors found a decrease in crashes for the youngest cyclists who were wearing a helmet and, among the youngest children, the proportion of cyclists using helmets was higher in the general population (i.e., not-responsible) than in those who were responsible for crashes. A limitation of this study includes using a quasi-induced methodology to estimate exposure.

Orsi et al (2014)

A cross-sectional study examined factors associated with alcohol use and helmet use in Germany for years 2000-2010. In this study, the sample included 242 cyclists involved in road accidents for whom alcohol test results were available taken from the German in-depth accident study, which covers a random sample of all accidents in the municipal areas of Hannover and Dresden. A multivariable analysis with alcohol use as the dependent variable showed that non-helmeted cyclists were more than twice as likely as helmeted cyclists to be intoxicated when riding. Another multivariable analysis with helmet use as the dependent variable showed that sober cyclists were two times more likely to wear a helmet, compared to intoxicated cyclists. In addition, the authors discuss a potential selection bias since it is unlikely a cyclist involved in a traffic crash are tested for alcohol use.

Gamble and Walker (2016)

The authors conducted a laboratory experiment that compared two groups of participants (one wearing a bicycle helmet and the other group wearing a baseball cap) to examine the association between the awareness of wearing protective equipment and risk taking as well as sensation seeking. The sample was comprised of 34 males and 46 females with an average age of 25.26 years. To examine the relationship between risk taking and wearing a bicycle helmet, participants in both groups were asked to press a button to inflate an animated balloon on a computer screen. The authors found that wearing a bicycle helmet was associated with higher risk-taking scores and higher sensation seeking than wearing a baseball cap.

This study has several limitations. It is not clear how the participants were recruited or how they were assigned to groups, it is unclear if participants changed from a baseline condition, there is the potential for experimenter bias since they were not blind to treatment, and the association between helmet wearing and risk-taking behaviour was not tested in a relevant context (cycling). Additionally, sensation seeking is conceptualised as a human trait, not a state (Zuckerman, 1984). Therefore, similar to other human traits, sensation seeking does not easily vary depending on the situation (i.e., wearing or not wearing a helmet); however, this trait is generally stable over time and in different situations. A critical review of this study can be found elsewhere (Radun & Lajunen, in press).

Lajunen (2016)

A cross-sectional self-report survey conducted in Norway aimed to compare adults' and children's reasons for wearing or not wearing a bicycle helmet. The study sample comprised 235 school children from two schools (one primary and one secondary) in the Sør-Trøndelag region in Norway and their parents (n = 106). The author found that both adults and children perceived their personal accident risk to be low and, therefore, there was no association between risk of getting seriously injured and helmet use. This study examined how wearing a helmet is related to safety feelings, instead of the association between wearing a helmet and risky behaviour. Therefore, the generalisability of the study results to the cycling population are limited.

Schleinitz et al (2017)

A naturalistic experimental study conducted in Germany examined the association between helmet wearing and cycling speed. The sample was comprised of 76 cyclists (32 females and 44 males) and a total of 3,416 trips (1,902 with a helmet and 1,514 without a helmet) over a four-week period. To conduct the experiment, bicycles were equipped with wheel sensors to record speed and distance as well as two cameras on the handlebar to record the cyclists' face and the forward scenery. The authors found that helmet wearing was correlated with longer trips and higher speed. However, a multiple linear regression analysis showed that helmet use had no effect on speed when controlling for other factors.

Salon and McIntyre (2018)

This study aimed to test the factors determining injury severity for pedestrians and cyclists using a cross-section of crash data in San Francisco, California for years 2005-2014. The data consisted of cyclists involved in a motor-vehicle collision. The authors found that 37% and 55% of helmeted and non-helmeted cyclists were at fault in the collision, respectively. That is, helmet wearers have a 52% reduction in the odds of being at fault in a crash versus non-wearers (OR = 0.48, 95% CI: 0.40-0.57). These findings show that non-helmeted cyclists were more likely to be at fault at the time of a motor-vehicle crash than a helmeted cyclist. The authors also found that 78% and 83% of helmeted and non-helmeted cyclists rode on the street without a bicycle lane/path, respectively.

4.4. Discussion

The peer-reviewed literature reporting bicycle helmet use and risky behaviour was systematically searched to assess the risk compensation hypothesis with respect to helmet wearing. Twenty-two studies were included with seventeen not supportive, three reporting mixed results, and two studies supportive of the risk compensation hypothesis. Brief summaries of the 22 included studies are provided in Table 4.1. The two supportive studies were both conducted in the United Kingdom by the same author. Overall, the current systematic review has found little to no support that bicycle helmet use is associated with engaging in risky behaviour.

Table 4.1. Characteristics of studies meeting selection criteria

Author	Country	Study Design	Results	Supports Hypothesis *
Gielen et al, 1994	United States	Cross-sectional study using self-report survey	Perceived risk of a bicycle injury was not associated with helmet use in Howard County and was negatively associated with helmet use in Baltimore and Montgomery counties	✗✓
Lardelli-Claret et al, 2003	Spain	Retrospective case series using crash data	Cycling at excessive or dangerous speed was not significantly associated with helmet use	✗
Klein et al, 2005	United States	Cross-sectional, study using self-report survey	31.5% increase on the risk-taking scale (alcohol/tobacco use, skipping school, and bullying) for non-helmet users	✗
Walker, 2007	United Kingdom	Naturalistic experiment	Motor vehicle drivers who overtook the author gave less space on average when he wore a helmet	✓
Buckley et al, 2009	Australia	Interventional experiment	Failing to wear a helmet was significantly associated with engaging in other transport-related risks	✗
Meneses Falcón et al, 2010	Spain	Stratified random sample survey	Helmet wearing was negatively associated with risky behaviour and positively related to safe behaviour	✗
Phillips et al, 2011	Norway	Field experimental study	Participants who used own helmet, cycled more slowly when cycling without a helmet; No differences among those who were not "accustomed to helmets"	✗
Crocker et al, 2012	United States	Prospective study using crash data	Alcohol use was negatively correlated with helmet use	✗
Fyhri et al, 2012	Norway	Cross-sectional study using, self-report survey	Traffic violations were negatively related to helmet use	✗
Messiah et al, 2012	France	Prospective cohort study	Speed was higher among helmeted than among non-helmeted male cyclists in low average speed areas, but not among females; It is unclear if the direction of the effect supports risk compensation	✗✓
Washington et al, 2012	Australia	Cross-sectional study using, self-report survey	Wearing a helmet is associated with a reduction in crash injury risk and an increase in perceived risk of cycling	✗
Bambach et al, 2013	Australia	Retrospective case-control study using crash data	Helmet use was positively associated with cycling in risky areas and negatively associated with disobeying a traffic control and alcohol use	✗✓
Fyhri et al, 2013	Norway	Field experimental study	Regular helmet users ride slower without a helmet and faster with a	✗

Author	Country	Study Design	Results	Supports Hypothesis *
			helmet; No association for non-users	
Martinez-Ruis et al, 2013	Spain	Cross-sectional study using crash data	Helmet wearing was not associated with traffic infractions or collision with another vehicle	✗
Webman et al, 2013	United States	Prospective cohort study	Helmet wearing was associated with riding with the flow of traffic and riding within bike lanes when available; Helmet use was associated with a non-significant decrease in the odds of alcohol use by 47%	✗
Chataway et al, 2014	Australia & Denmark	Cross-sectional study	Helmet wearing is positively and negatively associated with fear of traffic and distracted cycling, respectively.	✗
Martinez-Ruis et al, 2014	Spain	Cross-sectional study using crash data	Proportion of young cyclists using helmets was higher in the general population than in those who were responsible for crashes	✗
Orsi et al, 2014	Germany	Cross-sectional study using crash data	Cyclists who did not wear a helmet were more than twice as likely to be intoxicated as those who did	✗
Gamble & Walker, 2016	United Kingdom	Laboratory experimental study	Wearing a helmet was associated with higher risk-taking scores and higher sensation seeking than when wearing a baseball cap	✓
Lajunen, 2016	Norway	Self-report survey	Risk of getting seriously injured was not associated with helmet use	✗
Schleinitz et al, 2017	Germany	Naturalistic experiment	Helmet wearing was not associated with cycling speed	✗
Salon & McIntyre, 2018	United States	Cross-sectional study using crash data	Helmet wearers had a 52% reduction in the odds of being at fault in a crash versus non-wearers; There was no association between helmet wearing and riding on streets without a bicycle lane/path	✗

* Hypothesis tested: Bicycle helmet use is associated with risky behaviour

Key: ✓ (supportive evidence), ✗ (not supportive evidence), ✗✓ (mixed evidence)

Our search identified one non-peer reviewed report which was not included in our summary of articles (Walker, 1991). In this study, cyclists were observed before and after bicycle helmet legislation for adults in NSW. The proportions of cyclists complying with traffic rules was similar between the two surveys while helmet wearing had a 52% increase (25% in

1990 to 77% in 1991) for cyclists 16 years or older. That is, increased helmet wearing was not associated with an increase in illegal cycling behaviour.

The included studies assessed the association of helmet use and various forms of risky behaviour. Most studies, however, did not directly measure risk compensation through testing whether feeling safer while wearing a helmet leads to actual riskier behaviour (i.e., changes in behaviour); rather, these studies tested the risk compensation hypothesis by testing the association between helmet wearing and perceived risk of bicycle injury, but not on actual risk-taking behaviour (Gielen et al, 1994; Lajunen, 2016); by testing the relationship between helmet use and general risk-taking behaviour, not specifically cycling related risky behaviour (Klein et al, 2015); by using a cross-sectional design that did not examine changes in behaviour without and then with a helmet (Klein et al, 2005; Meneses Falcón et al, 2010; Fyhri et al, 2012; Messiah et al, 2012; Washington et al, 2012; Martinez-Ruis et al, 2013; Chataway et al, 2014; Martinez-Ruis et al, 2014; Orsi et al, 2014; Lajunen, 2016; Salon & McIntyre, 2018); or by collecting data on the association between helmet use and risky behaviour in a potentially irrelevant context (Gamble & Walker, 2016).

Additionally, the concept of risk compensation was tested in opposite and sometimes illogical directions for the purposes of this review, i.e., whether not wearing a helmet leads to less risky behaviour (Phillips et al, 2011; Fyhri et al, 2013) or whether alcohol leads to wearing a helmet or vice a versa (Orsi et al, 2014). It does not seem logical to assume that those who wear a helmet might feel safer and therefore might drink alcohol, or those who already drank alcohol might compensate by choosing to wear a helmet. However, there is doubt that any supporter of risk compensation would predict any of these compensatory mechanisms.

Finally, barriers for helmet use have not been tested in most studies. Specifically, it is unclear whether wearing or not wearing a helmet is due to the level of feeling safe or if there are other factors involved. As stated by Lajunen (2016), barriers for helmet wearing are more related to lack of comfort such as being too cold or too hot, or not fitting a hairstyle. However, subjective risk of getting into a crash and suffering serious injuries were not factors for wearing a helmet. Therefore, to increase helmet wearing, improvement in helmet design should be taken into consideration.

4.5. Limitations

There are several limitations to this systematic review. First, as mentioned in the discussion section, risk compensation has not been directly measured in the literature which may provide inaccurate results. Second, most articles identified in this search were commentaries regarding other studies without providing any data on the association between bicycle helmet wearing and risky behaviour. Only 22 studies were identified that provided first instance data. Third, due to ethical issues, the causal relationship between helmet use and risky behaviour is difficult to establish since participants cannot be randomised to wear or not wear a helmet.

4.6. Conclusions

Supporters of risk compensation argue against bicycle helmet wearing as they hypothesise the protective benefit is offset by risky behaviour. This systematic review of the peer-reviewed literature found little to no supportive evidence of the risk compensation hypothesis. Although two out of the 22 studies were supportive of risk compensation, ten other studies found helmet wearing was associated with safer cycling behaviour.

Chapter 5: Discussion and Conclusion

The aims of this study were to (1) systematically identify and describe bicycle helmet laws worldwide, (2) perform a systematic review of the effects of bicycle helmet legislation on cycling exposure, and (3) perform a systematic review of bicycle helmet use and the risk compensation hypothesis.

Bicycle helmet laws were identified in 28 countries with nine having all-ages legislation and an additional six countries with all-ages legislation depending on location or whether the cyclist is travelling in an urban or interurban area. These laws vary substantially in regards to the maximum applicable age, existence of enforcement measures, and the monetary value of fines. Out of a total 273 laws, only two have been fully repealed. No assessments on the impact of the repealed laws on cycling exposure or injury/fatality have been identified so far. Although often categorised as a rarity, bicycle helmet laws exist in roughly half of the OECD, IRTAD and EU nations.

The systematic review of the impact of bicycle helmet legislation identified 23 collections of studies from seven countries. Bicycle helmet legislation did not negatively impact cycling in thirteen of these studies while eight studies found both evidence for and against a negative impact of helmet legislation. Only two studies identified a consistent reduction in cycling following legislation; however, other studies from these jurisdictions failed to estimate a consistent reduction in cycling following legislation.

It is still possible there exist cyclists deterred by bicycle helmet laws and it is certainly true there exist cyclists who are against either the promotion or legislation for their use. This can be readily affirmed by any cursory internet search. However, the results from this systematic review do not estimate any large reductions in cycling due to legislation or that those opposed to helmet use or legislation constitute a large proportion of the population.

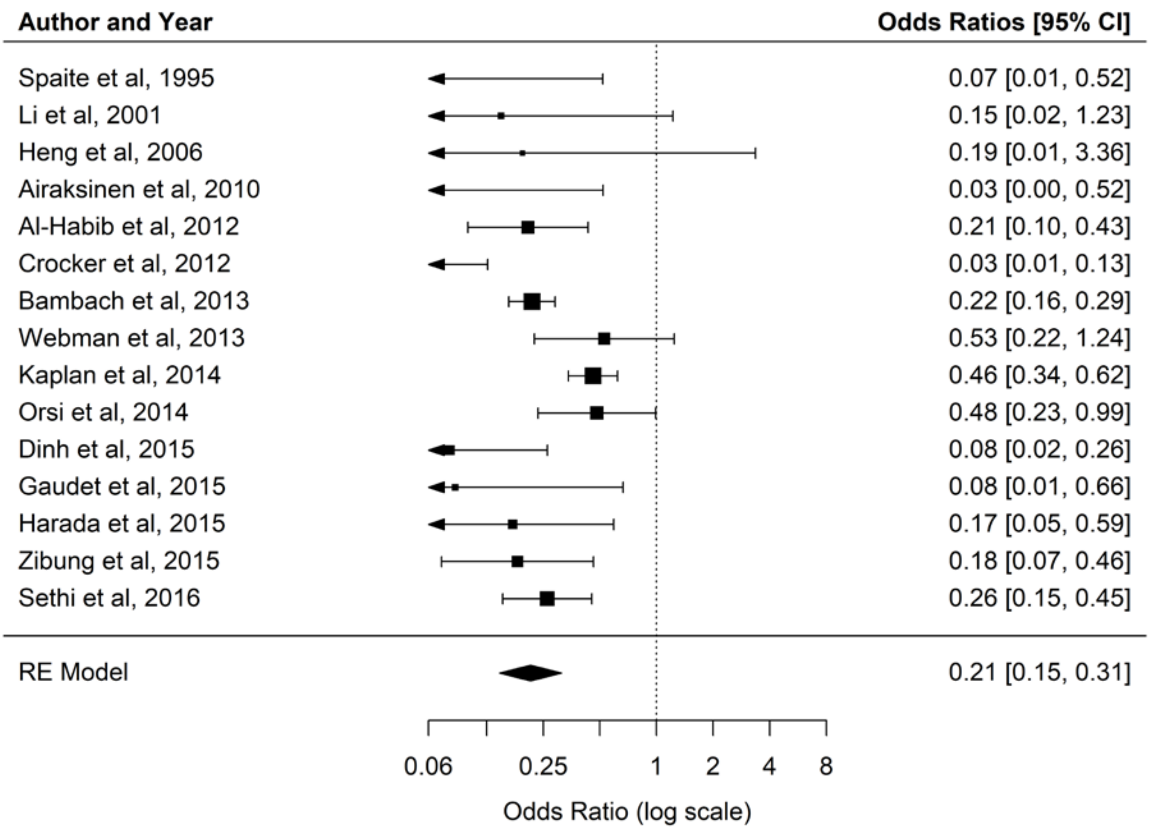
Importantly, most countries with helmet legislation have not been represented in this review, so caution should be exercised when interpreting these results.

Like the review on bicycle helmet laws, the systematic review on bicycle helmet use and risk compensation could identify very little supportive evidence. Out of 22 included studies, only two were supportive of the risk compensation hypothesis while seventeen studies were unsupportive, and the results were mixed for three studies.

There are important implications of this review on bicycle helmet effectiveness. Case-control studies of crash data can accurately estimate helmet effectiveness if helmet use and having a crash are independent events (Olivier, 2017). However, if helmeted cyclists are more risk averse than unhelmeted cyclists, then case-control studies of crash data underestimate bicycle helmet effectiveness. Ten included studies found helmet use was associated with safer behaviour than unhelmeted cyclists, while only two studies found helmet use was associated with riskier behaviour. If it can reasonably be assumed risky behaviour increases the likelihood of a bicycle crash, then bicycle helmets are more effective than previously believed.

In addition to the reviews presented in this report, a systematic review of bicycle helmet and alcohol use was undertaken. At the time of this writing, however, this systematic review is incomplete. Preliminary results are given in Figure 6.1 that summarises data found in fifteen studies. The summary results suggest bicycle helmet wearing is associated with a 79% reduction in the odds of drinking alcohol and cycling (OR = 0.21, 95% CI: 0.15-0.31).

Figure 6.1. Forest plot of the association between helmet use and alcohol use



Although the results from these reviews are positive with regards to bicycle helmet legislation and the use of helmets more generally, it is clear from other research that the promotion or legislation of bicycle helmets are inadequate as a cycling safety strategy in isolation. Segregated cycling infrastructure can help mitigate collisions between unpowered two or more wheeled vehicles and motorised vehicles, which often result in serious injury for the vulnerable road user. Purpose-built cycling infrastructure has the additional benefit of making cycling more attractive to the casual cyclist.

Legislation that is supportive of cycling, in jurisdictions where this does not already exist, should also be explored. This includes minimum passing distances for motor vehicles overtaking cyclists and presumed liability where the onus is on the motor vehicle driver to demonstrate inculpability in a motor vehicle/bicycle crash.

Current helmet technology could also be improved. The latest systematic review estimates helmet use reduces head injury and serious head injury by about 50% and 70% respectively in a crash or fall (Olivier & Creighton, 2017). This could be accomplished by first harmonising the existing helmet standards and creating a rating system. Manufacturers would work to improve their helmets to receive a top star rating which would be a selling point for them. Star ratings have been demonstrated to improve safety in other areas such as motor vehicle crash technologies and motorcycle helmets (SAFER). Additionally, alternative methods could be further explored such as the Hövding airbag helmet which is perhaps more comfortable for some cyclists and has been shown to be highly protective against forces to the head in biomechanical testing (Stigson et al, 2017; Kurt et al, 2017).

The implications of this review, along with the results from other reviews and studies, are supportive of strategies to increase bicycle helmet usage including legislation. However, due to the wide variety of existing laws with regards to enforcement and applicable ages, no recommendations can be made regarding the optimality of any specific form of legislation with regards to those factors.

References

Acton C. Helmet laws and health. *Inj Prev* 1998;4(3):171-172.

Adams J, Hillman M (a). The risk compensation theory and bicycle helmets. *Inj Prev* 2001;7:89–91.

Adams J, Hillman M (b). Letters to the editor: The risk compensation theory and bicycle helmets. *Inj Prev* 2001;7:343–344.

Adams J, Hillman M (c). Bicycle helmets: Risk taking is influenced by people's perception of safety and danger. *BMJ* 2001;322:1063-1064.

Adena M, Montesin H. Day-to-Day Travel in Australia 1985-86. Canberra: Instat Australia Pty Ltd, Federal Office of Road Safety, 1988.

Ahillen M, Mateo-Babiano D, Corcoran J. Dynamics of bike sharing in Washington, DC and Brisbane, Australia: Implications for policy and planning. *Int J Sustainable Transportation* 2016;10(5):441-454.

Airaksinen N, Luthje P, Nurmi-Luthje I. Cyclist injuries treated in Emergency Department (ED): Consequences and costs in South-Eastern Finland in an area of 100 000 inhabitants. *Ann Adv Automot Med* 2010;54:267-274.

Al-Habib A, Attabib N, Hurlbert RJ. Recreational helmet use as a predictor of noncranial injury. *J Trauma Acute Care Surg* 2012;72:1356-1362.

Amy Gillett Foundation. A metre matters, Victoria Community Attitudes Research. November 2016.

Attard J, Deguara M, Buontempo MB. Cyclist Safety in Malta: A Review. *Malta Med J*. 2016;28(4).

Attewell R, Glase K, McFadden M. Bicycle helmet efficacy: a meta-analysis. *Accid Anal Prev*. 2001;33:345–352.

Australian Bureau of Statistics (ABS). Population growth and distribution in Australia, 1991. Available from: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/2035.0Main+Features11991?OpenDocument

Australian Bureau of Statistics (ABS). Method of travel to work. 2012 October 24 [cited 2018 February 8]. Available from http://abs.gov.au/websitedbs/censushome.nsf/home/statementspersonmtwp?opendocument&navpos=430

Australian Capital Territory Government. Cycling Reform Pre-Trial Study [Presentation]. 2015 September.

Australian Capital Territory Government. Cycle Reforms Post-Trial Study [Presentation]. 2017 November.

Australian Transport Safety Bureau. Australian Government. 2006 June [cited 2017 August 23]. Available from: https://infrastructure.gov.au/roads/safety/publications/2006/pdf/death_cyclists_road.pdf.

Bambach MR, Mitchell RJ, Grzebieta RH, Olivier J. The effectiveness of helmets in bicycle collisions with motor vehicles: a case-control study*. Accid Anal Prev* 2013;53:78-88.

Barczyk AN, Yuma-Guerrero P, von Sternberg K, Velasquez MM, Brown J, Maxson T, Lawson KA. Risky drinking among parents of pediatric trauma patients. *J Trauma Acute Care Surg*. 2013;75:676-81.

Bateman-House A. Bikes, helmets, and public health: Decision-making when goods collide. *Am J Public Health*2014;104:986-992.

Bauer R, Steiner M, Robatsch K. Five years of mandatory bicycle helmets for children in Austria–a post hoc evaluation. *Inj Prev* 2016;22(Suppl 2):A90.

Bicycle Helmet Safety Institute. Bicycle Helmet Laws. 2017 April. [cited 2017 August 23]. Available from: https://helmets.org/mandator.htm.

Biegler P, Johnson M. In defence of mandatory bicycle helmet legislation: response to Hooper and Spicer. *J Med Ethics* 2015;41:713-717.

Bonander C, Nilson F, Andersson R. The effect of the Swedish bicycle helmet law for children: An interrupted time series study. *J Saf Res* 2014;51:15–22.

Boufous S, de Rome L, Senserrick T, Ivers R. Risk factors for severe injury in cyclists involved in traffic crashes in Victoria, Australia. *Accid Anal Prev*. 2012;49:404-409.

Boufous S, Olivier J. Recent trends in cyclist fatalities in Australia. *Inj Prev* 2016;22:284-287.

Buckley L, Sheehan M, Chapman R. Bicycle Helmet Wearing Among Adolescents: Effectiveness of School-Based Injury Prevention Countermeasure. *Transportation Res Record* 2009;(2140):173-81.

Bureau of Infrastructure, Transport and Regional Economics (BITRE). Walking, Riding and Access to Public Transport, Draft report for discussion – October 2012. Commonwealth of Australia, 2012.

Cameron MH, Heiman L, Neiger D. Evaluation of the bicycle helmet wearing law in Victoria during its first 12 months. Monash University Accident Research Centre. 1992.

Cameron M, Newstead S, Vulcan P, Finch C (b). Effects of the compulsory bicycle helmet wearing law in Victoria during its first three years. Australian Pedestrian and Bicyclist Safety and Travel Workshop, Melbourne, Australia. 1994.

Cameron MH, Vulcan AP, Finch CF, Newstead SV (a). Mandatory bicycle helmet use following a decade of helmet promotion in Victoria, Australia—an evaluation. *Accid Anal Prev* 1994;26(3):325-37.

Carnall D. Cycle helmets should not be compulsory. *BMJ* 1999;318:1505.

Carpenter CS, Stehr M. Intended and unintended consequences of youth bicycle helmet laws. *J Law Economics*. 2011;54(2):305-24.

Carr DJ, Cameron MH, Skalova M. Evaluation of the bicycle helmet wearing law in Victoria during its first four years. Monash University Accident Research Centre. 1995 Aug.

Chapman HR, Curran AL. Bicycle helmets—does the dental profession have a role in promoting their use? *BDJ*. 2004;196(9):555.

Chataway ES, Kaplan S, Nielsen TA, Prato CG. Safety perceptions and reported behavior related to cycling in mixed traffic: A comparison between Brisbane and Copenhagen. *Trans Res F: Traffic Psych Behaviour* 2014;1;23:32-43.

Clarke CF. Evaluation of New Zealand's bicycle helmet law. *NZ Med J* 2012;125:1-10.

Clarke CF. Reply to Wang et al response to 'Evaluation of New Zealand's bicycle helmet law' article. *NZ Med J* 2014;127:113-6.

Clinch PJ. Do enforced bicycle helmet laws improve public health? Start with an assessment of the base problem, rather than assume a solution. *BMJ* 2006;332(7545):852.

Consumer Rating and Assessment of Safety Helmets (CRASH). SAFER motorcycle helmets. [cited 2018 March 13]. Available from: https://www.crash.org.au/rating-system.html

Cosgrove DC. Long-term patterns of Australian public transport use. Australasian Transport Research Forum. Adelaide, Australia 2011.

Cripton PA, Dressler DM, Stuart CA, Dennison CR, Richards D. Bicycle helmets are highly effective at preventing head injury during head impact: head-form accelerations and injury criteria for helmeted and unhelmeted impacts. *Accid Anal Prev* 2014;70:1–7.

Crocker P, King B, Cooper H, Milling TJ. Self-reported alcohol use is an independent risk factor for head and brain injury among cyclists but does not confound helmets' protective effect. *J Emerg Med*. 2012;43:244-50.

Curnow WJ. Helmets not helpful-an example of poor public policy. *Health Promot J Australia* 2005;16(2):160.

Curnow WJ. Bicycle helmets and public health in Australia. *Health Promot J Austr* 2008;19(1):10.

Cyclists' Rights Action Group. Five ways wearing a bicycle helmet can result in injuries. 2013 April 28. [cited 2018 February 5]. Available from: http://crag.asn.au/category/helmets.

Davis A. Cyclist should wear helmets: Increasing the number of cyclists is more important. *BMJ* 1997;314:69.

Davis RM, Pless B. Evidence shows that cyclists should wear helmets. *BMJ* 1996;313:629.

de Jong P (a). The Health Impact of Mandatory Bicycle Helmet Laws. *Risk Anal* 2012;32:782-790.

de Jong P (b). Response. *Risk Anal* 2012;32:799-800.

De Hartog JJ, Boogaard H, Nijland H, Hoek G. Do the health benefits of cycling outweigh the risks? *Environ Health Perspect* 2010;118:1109.

DeMarco T. Helmet legislation could decrease cycling. *Can Family Phys* 1994;40:1703.

Dennis J, Potter B, Ramsay T, Zarychanski R. The effects of provincial bicycle helmet legislation on helmet use and bicycle ridership in Canada. *Inj Prev* 2010;16:219-224.

Dinh MM, Kastelein C, Hopkins R, Royle TJ, Bein KJ, Chalkley DR, Ivers R. Mechanisms, injuries and helmet use in cyclists presenting to an inner city emergency department. *Emerg Med Aust* 2015;27:323–27.

Elbers RG, van Enst A. In het kort, helmplicht voor fietsers, effect op hoofdletsel en fietsgebruik. *Ned Tijdschr Geneeskd* 2010;154:A2728.

Essential Vision. Essential Report 30 April 2012. Available from: http://essentialvision.com.au/documents/essential_report_120430.pdf

European Commission. Road safety in the European Union; Trends, statistics and main challenges. 2015 March. [cited 2018 February 7]. Available from: https://ec.europa.eu/transport/sites/transport/files/road_safety/pdf/vademecum_2015.pdf.

European Commission. Road safety in the European Union; Trends, statistics and main challenges. 2016 November. [cited 2018 February 7]. Available from: https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/vademecum_2016.pdf.

European Union. Countries. 2018 January. [cited 2018 January 31]. Available from: https://europa.eu/european-union/about-eu/countries_en#tab-0-1.

Finch CF. Teenagers' attitudes towards bicycle helmets three years after the introduction of mandatory wearing. *Inj Prev* 1996;2:126-30.

Finch CF, Heiman L, Neiger D. Bicycle use and helmet wearing rates in Melbourne, 1987-1992: the influence of the helmet wearing law. Monash University Accident Research Centre 1993 Feb.

Finnish Government (a). Hallituksen esitys eduskunnalle tieliikennelaiksi ja eräiksi siihen liittyviksi laeiksi [The Government's proposal to the Parliament regarding road traffic law and some related laws]. 2017 Feb [cited 2017 April 27]. Available at: https://www.lausuntopalvelu.fi/FI/Proposal/DownloadProposalAttachment?attachmentId=3010.

Finnish Government (b). Hallituksen esitys eduskunnalle tieliikennelaiksi ja eräiksi siihen liittyviksi laeiksi HE 180/2017 [The Government's proposal to the Parliament for road traffic laws and some related laws] 2017 Nov [cited 2018 February 14]. Available from: http://valtioneuvosto.fi/paatokset/paatos?decisionId=0900908f8055d6e6

Fishman E. Bikeshare: A Review of Recent Literature. *Transport Rev* 2016.36:92-113.

Fishman E, Washington S, Haworth N. Bike Share: A Synthesis of the Literature. *Transport Rev*. 2013;33:148-165.

Fishman E, Cherry C. E-bikes in the Mainstream: Reviewing a Decade of Research. *Transport Rev* 2016;36:72-91.

Fyhri A, Bjørnskau T, Backer-Grøndahl A. Bicycle helmets – A case of risk compensation? *Transport Res F* 2012;15:612-624.

Fyhri A, Phillips RO. Emotional reactions to cycle helmet use. *Accid Anal Prev* 2013;50:59-63.

Gamble T, Walker I. Wearing a bicycle helmet can increase risk taking and sensation seeking in adults. *Psych Science* 2016;27289-94.

Gaudet L, Romanow NT, Nettel-Aguirre A, Voaklander D, Hagel BE, Rowe BH. The epidemiology of fatal cyclist crashes over a 14-year period in Alberta, Canada. *BMC Public Health* 2015;15:1142.

Geary R. Do enforced bicycle helmet laws improve public health? Determining true effectiveness of safety measures. *BMJ* 2006;332:852.

Gielen AC, Joffe A, Dannenberg AL, Wilson ME, Beilenson PL, DeBoer M. Psychosocial factors associated with the use of bicycle helmets among children in counties with and without helmet use laws. *J Pediatrics* 1994;124:204-10.

Gillham C, Rissel C. Australian per capita cycling participation in 1985/86 and 348 2011. World Transport Policy and Practice 2012;18:5-13.

Goodwin A, Thomas L, Kirley B, Hall W, O'Brien N, Hill K. Countermeasures that work: A highway safety countermeasure guide for State highway safety offices, Eighth edition. (Report No. DOT HS 812 202). Washington, DC: National Highway Traffic Safety Administration, 2015.

Graitcer PL, Kellermann AL, Christoffel T. A review of educational and legislative strategies to promote bicycle helmets. *Inj Prev* 1995;1:122.

Greaves S. Draconian new bike laws won't improve safety. The Sydney Morning Herald. 2016 February [cited 2018 January 31]. Available from http://www.smh.com.au/comment/draconian-new-bike-laws-wont-improve-safety-20160229-gn6jke.html.

Guy, K. Open drum: why I refuse to wear a bike helmet. ABC News. 2015 June 12 [cited 2017 August 15]. Available from: http://www.abc.net.au/news/2015-06-12/guy-k-why-i-refuse-to-wear-a-bike-helmet/6541246.

Hagel B, Macpherson A, Rivara FP, Pless B. Arguments against helmet legislation are flawed. *BMJ* 2006;332:725.

Hagel BE, Pless IB. A critical examination of arguments against bicycle helmet use and legislation. *Accid Anal Prev* 2006;38:277-8.

Hagel BE, Yanchar NL, Canadian Paediatric Society, Injury Prevention Committee. Bicycle helmet use in Canada: the need for legislation to reduce the risk of head injury. *Paediatrics & Child Health* 2013;18:475-80.

Hall GH. Cyclist should wear helmets: Do gooders' intolerance is counter productive to their aims. *BMJ* 1997;314:70.

Harada MY, Gangi A, Ko A, Liou DZ, Barmparas G, Li T, Hotz H, Stewart D, Ley EJ. Bicycle trauma and alcohol intoxication. *Int J Surg* 2015;24:14–19.

Harrison R. Observational study of bicycle helmet wearing amongst South Australian school children. Report from Harrison Market Research prepared for the Office of Road Safety, South Australian Department of Transport, Walkerville, SA. 1994.

Haworth NL, Schramm AJ, King MJ, Steinhardt DA. Bicycle helmet research: CARRS-Q monograph 5. Centre for Accident Research and Road Safety-Queensland, Queensland University of Technology. 2010.

Healy M, Maisey G. The impact of helmet wearing legislation and promotion on bicyclists in Western Australia. Research and Statistics Unit WA Police Department. 1992.

Heathcote B. Bicyclist helmet wearing in Western Australia: a 1993 review. Traffic Board of Western Australia, Research and Statistics Unit WA Police Department. 1993.

Heathcote B, Maisey G. Bicycle use and attitudes to the helmet wearing law. Traffic Board of Western Australia, Research and Statistics Unit WA Police Department. 1994.

Heng KWJ, Lee AHP, Zhu S, Tham KY, Seow E. Helmet use and bicycle-related trauma in patients presenting to an acute hospital in Singapore. *Singapore Med J* 2006;47:367–372.

Hillman M (a). Cycling offers important health benefits and should be encouraged. *BMJ*1997;315:490.

Hillman M (b). Cyclists should wear helmets: Health benefits of cycling greatly outweigh loss of life years from deaths. *BMJ* 1997;314:70.

Hooper C, Spicer J. Liberty or death; don’t tread on me. *J Med Ethics* 2012;38:338-341

Høye A. Trafikksikkerhet for syklister. Transportøkonomisk Institutt (TØI rapport 1597/2017), 2017.

Huybers S, Fenerty L, Kureshi N, Thibault-Halman G, LeBlanc JC, Clarke DB, Walling S. Long-Term Effects of Education and Legislation Enforcement on All-Age Bicycle Helmet Use: A Longitudinal Study. *J Community Health* 2017;42:83-89.

International Cycling Safety Conference (ICSC). Cycle helmet safety: global harmonization of consumer information rating schemes, 2017. [cited 16 February 2018] Available from: http://icsc2017.ucdavis.edu/helmet-workshop/

International Transport Forum. IRTAD members. 2018 [cited 2018 31 January]. Available from: https://www.itf-oecd.org/irtad-members.

International Transport Forum. Road Safety Annual Report 2017, OECD Publishing, Paris. 2017 [cited 2018 31 January]. Available from: http://dx.doi.org/10.1787/irtad-2017-en.

Jenkins RR, Owns N, Wiggins LB. Valuing reduced risks to children: The case of bicycle safety helmets. Contemporary Econ Policy 2001;19:397-408.

Johnston BD. Living in the grey area: a case for data sharing in observational epidemiology. Inj Prev 2012;18:358-359.

Kaplan S, Vavatsoulas K, Prato CG. Aggravating and mitigating factors associated with cyclist injury severity in Denmark. *J Safety Res* 2014;50:75-82.

Karkhaneh M. Bicycle helmet use and bicyclists head injuries before and after helmet legislation in Alberta Canada (Doctoral dissertation, University of Alberta). 2011.

Karkhaneh M, Rowe BH, Saunders LD, Voaklander DC, Hagel BE. The association between bicycle helmet legislation and the rate of cycling in Alberta, Canada (Poster presentation no. 125). *Can J Emerg Med* 2010;12:266.

Karkhaneh M, Rowe BH, Saunders LD, Voaklander DC, Hagel BE. Trends in head injuries associated with mandatory bicycle helmet legislation targeting children and adolescents. *Accid Anal Prev* 2013;59:206-212.

Keatinge R. Cycle helmets. Deter people from cycling. *BMJ* 1994;309:541.

Keatinge R. Cyclists should wear helmets: Better to control the demand for fast cars. *BMJ* 1997;314:70.

Kett P, Rivara F, Gomez A, Kirk AP, Yantsides C. The effect of an all-ages bicycle helmet law on bicycle-related trauma. *J Community Health* 2016;41:1160-1166.

King M, Fraine G. Bicycle helmet legislation and enforcement in Queensland 1991 to 1993: Effects on helmet wearing and crashes. Australian Pedestrian and Bicyclist Safety and Travel Workshop, Melbourne, Australia 1994.

Klein KS, Thompson D, Scheidt PC, Overpeck MD, Gross LA. Factors associated with bicycle helmet use among young adolescents in a multinational sample. *Inj Prev* 2005;11:288-93.

Kraemer JD. Helmet laws, helmet use, and bicycle ridership. *J Adoles Health* 2016;59:338-44.

Kurt M, Laksari K, Kuo C, Grant GA, Camarillo DB. Modeling and optimization of airbag helmets for preventing head injuries in bicycling. *Annal Biomed Engineering* 2017;45:1148-1160.

Lajunen T. Barriers and facilitators of bicycle helmet use among children and their parents. *Trans Res F: Traffic Psych Behaviour* 2016;41:294-301.

Land Transport New Zealand. Sustainable and safe land transport trends and indicators. 2007 June. [cited 2018 February 7]. Available from: http://www.cycle-helmets.com/nz-ltsa-2006.pdf.

Laolert P. An assessment of bicycle helmet legislation on cycling head injuries in Western Australia. Unpublished master's thesis, School of Mathematics and Statistics, University of New South Wales, 2014.

Lardelli-Claret P, Luna-del-Castillo JD, Jimenez-Moleon JJ, Garcia-Martin M, Bueno-Cavanillas A, Galvez-Vargas R. Risk compensation theory and voluntary helmet use by cyclists in Spain. *Inj Prev* 2003:9:128–132.

Laurie S. The effect of compulsory bicycle helmet legislation on injuries of patients hospitalised in South Australia following cycling accidents. Research Project for 4th year medicine, Flinders University, conducted in conjunction with the injury control unit of the SA Health Commission. 1992.

Lemon J. Changes in participation, demographics and hazard associated with mandatory bicycle helmets in New South Wales, Australia. *J Transp Health*, in press.

Li G, Baker SP, Smialek JE, Soderstrom CA. Use of alcohol as a risk factor for bicycling injury. *JAMA* 2001;285:893-896.

Luchemos por la vida. Lo que dice la ley [What the law says] [cited 2018 21 February]. Available from: http://www.luchemos.org.ar/es/sabermas/conducir-seguro-en-bicicleta/lo-que-dice-la-ley.

Macpherson AK, Parkin PC. Helmet laws and cycle use. *Inj Prev* 2003;9:380-381.

Macpherson AK, Parkin PC, To TM. Mandatory helmet legislation and children's exposure to cycling. *Inj Prev* 2001;7:228-230.

Macpherson AK, Macarthur C, To TM, Chipman ML, Wright JG, Parkin PC. Economic disparity in bicycle helmet use by children six years after the introduction of legislation. *Inj Prev* 2006;12:231-5.

Macpherson A, Spinks A. Bicycle helmet legislation for the uptake of helmet use and prevention of head injuries. *Cochrane Database Syst Rev* 2008;CD005401.

Maisey G. Bicycle helmet wearing legislation & promotion experience in Western Australia. Australian Institute of Traffic Planning and Management (AITPM) National Conference, 6th, 1993, Gold Coast, Australia. 1993.

Marshall J, White M. Evaluation of the compulsory helmet wearing legislation for bicyclists in South Australia. Office of Road Safety. 1994 Aug.

Marshall SW. Injury Case-Control Studies Using "Other Injuries" as Controls. *Epidemiol* 2008;19:277-279.

Martínez-Ruiz V, Jiménez-Mejías E, de Dios Luna-del-Castillo J, García-Martín M, Jiménez-Moleón JJ, Lardelli-Claret P. Association of cyclists' age and sex with risk of involvement in a crash before and after adjustment for cycling exposure. *Accid Anal Prev* 2014;62:259-267.

Martínez-Ruiz V, Lardelli-Claret P, Jiménez-Mejías E, Amezcua-Prieto C, Jimenez-Moleon JJ, del Castillo JD. Risk factors for causing road crashes involving cyclists: An application of a quasi-induced exposure method. *Accid Anal Prev* 2013;51:228-237.

McCarthy M. Pedal cyclists, crash helmets and risk. *Public Health* 1991;105:327-34.

McDermott FT. Bicyclist head injury prevention by helmets and mandatory wearing legislation in Victoria, Australia. *Annal Royal College Surg England*. 1995;77:38.

McIntosh AS, Lai A, Schilter E. Bicycle helmets: head impact dynamics in helmeted and unhelmeted oblique impact tests. *Traffic Inj Prev* 2013;14:501-508.

McNally DS, Rosenberg NM. MADYMO simulation of children in cycle accidents: A novel approach in risk assessment. *Accid Anal Prev* 2013;59:469–478.

McNally DS, Whitehead S. A computational simulation study of the influence of helmet wearing on head injury risk in adult cyclists. *Accid Anal Prev* 2013;60:15–23.

Mees P, Groenhart L. Transport Policy at the Crossroads: Travel to work in Australian capital cities 1976–2011. RMIT University, Melbourne (2012).

Melo N, Berg RJ, Inaba K. Injuries sustained by bicyclists. *Trauma* 2014;16:183-188.

Meneses Falcón C, García EG, Avilés NR. Adolescentes, situaciones de riesgo y seguridad vial. *Atención Primaria* 2010;42:452-458.

Messiah A, Constant A, Contrand B, Felonneau ML, Lagarde E. Risk Compensation: A Male Phenomenon? Results From a Controlled Intervention Trial Promoting Helmet Use Among Cyclists. *Am J Public Health* 2012;102:S204-S206.

Ministry of the Interior. A vélo, le casque obligatoire pour les moins de 12 ans [By bike, helmet compulsory for children under 12]. 2016 December 22. [cited 2018 January 31]. Available from: https://www.interieur.gouv.fr/Archives/Archives-des-actualites/2016-Actualites/A-velo-le-casque-obligatoire-pour-les-moins-de-12-ans.

Minerva. *BMJ* 1996; 312:1310.

Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA Statement. *PLOS Med* 2009;6.

Molina-García J, Queralt A. The impact of mandatory helmet-use legislation on the frequency of cycling to school and helmet use among adolescents. *J Phys Act Health* 2016;13:649-53.

Moyes SA. Changing pattern of child bicycle injury in the Bay of Plenty, New Zealand. *J Paediatr Child Health* 2007;43:486-488.

Munro C. Australian Cycling Participation 2011. Canberra: Austroads, 2011.

National Heart Foundation. Riding a Bike for Transport 2011. Survey Findings. Available from: https://www.heartfoundation.org.au/images/uploads/publications/Cycling-Survey-2011-Riding-a-Bike-for-Transport.pdf

National Heart Foundation. Women and cycling survey 2013. Available from: https://www.heartfoundation.org.au/images/uploads/publications/Cycling-Survey-2013-Women-and-Cycling.pdf

Newbold SC. Examining the Health-Risk Tradeoffs of Mandatory Bicycle Helmet Laws. *Risk Anal* 2012;32:791-8.

New Zealand Ministry of Transport. Cycle helmet use survey. 2015 [cited 2018 January 31]. Available from: http://www.transport.govt.nz/research/roadsafetysurveys/cyclehelmetusesurvey2015/.

Northern Territory Government. Bicycle safety. 2017 November 28. [cited 2018 February 6]. Available from: https://nt.gov.au/driving/safety/bicycle-safety.

oBike. 2017 [cited 2017 September 26]. Available from: https://www.o.bike/au/about.html.

OECD. List of OECD Member countries - Ratification of the Convention on the OECD. 2018 [cited 2018 January 31]. Available from: http://www.oecd.org/about/membersandpartners/list-oecd-member-countries.htm.

Oja P, Titze S, Bauman A, de Geus B, Krenn P, Reger-Nash B, Kohlberger T. Health benefits of cycling: a systematic review. *Scand J Med Sci Sports* 2011;21:496-509.

Olivier J. The apparent ineffectiveness of bicycle helmets: A case of selective citation. *Gac Sanit* 2014;28:254-5.

Olivier J, Boufous S, Grzebieta RH. No strong evidence bicycle helmet legislation deters cycling. *MJA* 2016;205:54-55.

Olivier J, Churches T, Walter S, McIntosh A, Grzebieta R. Response to Rissel and Wen: The possible effect on frequency of cycling if mandatory bicycle helmet legislation was repealed in Sydney, Australia: a cross sectional survey. *Health Promot J Austr* 2012;23:76.

Olivier J, Creighton P. Bicycle injuries and helmet use: a systematic review and meta-analysis. *Int J Epidemiol* 2017;46:278-92.

Olivier J, Creighton P, Mason CT. Evidence bicycle helmets mitigate intra-cranial injury is not controversial. *Eur J Trauma Emerg Surg* 2016;42:333-336.

Olivier J, Hayen A, Walter S, Churches T, Grzebieta R. Cycling rates are up, despite creaky knees. ABC Environment, 2012. Available at: https://web.archive.org/web/20140719035541/http://www.abc.net.au/environment/articles/2012/07/18/3546884.htm

Olivier J, Terlich F. The Use of Propensity Score Stratification and Synthetic Data to Address Allocation Bias when Assessing Bicycle Helmet Effectiveness. 2016 IRCOBI Conference Proceedings–International Research Council on the Biomechanics of Injury. 2016;185-193.

Olivier J, Walter SR. Bicycle helmet wearing is not associated with close motor vehicle passing: a re-analysis of Walker, 2007. *PLOS One* 2013;8:e75424.

Olivier J, Walter SR, Grzebieta R. Long term bicycle related head injury trends for New South Wales, Australia following mandatory helmet legislation. *Accid Anal Prev* 2013;50:1128-1134.

Olivier J. The role of probability and statistics in bicycle helmet research. Australasian Road Safety Conference, 2017, Perth, Australia.

Orsi C, Ferraro OE, Montomoli C, Otte D, Morandi A. Alcohol consumption, helmet use and head trauma in cycling collisions in Germany. *Accid Anal Prev* 2014;65:97-104.

Persaud N, Coleman E, Zwolakowski D, Lauwers B, Cass D. Nonuse of bicycle helmets and risk of fatal head injury: a proportional mortality, case–control study. *Can Med Assoc J* 2012;184:E921-3.

Petersen T. Cyklandets utveckling i Sverige 1995–2014 – en analys av de nationella resvaneundersökningarna. 2015 [cited 2018 February 7]. Available from: https://www.trafa.se/globalassets/rapporter/2010-2015/2015/rapport-2015_14-cyklandets-utveckling-i-sverige-1995-2014.pdf.

Pettersen AJS. Flertal af danskerne: Cykelhjelm skal være lovpligtig, 2017 [cited 16 February 2018] Available from: https://www.avisen.dk/flertal-af-danskerne-goer-det-lovpligtigt-at-bruge-c_436213.aspx

Phillips RO, Fyhri A, Sagberg F. Risk Compensation and Bicycle Helmets. *Risk Anal* 2011;31:1187-1195.

Pless B, Davis R. Cyclists should wear helmets. *BMJ* 1997;314:977.

Povey LJ, Frith WJ, Graham PG. Cycle helmet effectiveness in New Zealand. *Accid Anal Prev* 1999;31:763-70.

Radun I, Lajunen T. Bicycle Helmets and the Experimenter Effect. *Psychol Sci*, in press. https://doi.org/10.1177/0956797618761040

Radun I, Olivier J. Bicycle helmet law does not deter cyclists in Finland. *PsyArXiv* 2018. http://doi.org/10.17605/OSF.IO/46HG5

Radun I, Radun J, Esmaeilikia M, Lajunen T. Risk compensation and bicycle helmets: a false conclusion and uncritical citations. *PsyArXiv* 2018. http://doi.org/10.17605/OSF.IO/2N693

Raven T. Do enforced bicycle helmet laws improve public health? Evidence is conflicting. *BMJ* 2006;332:852.

Reddy Go. 2017 [cited 2017 September 21]. Available from: https://www.reddygo.com.au/.

Reid, C. Bosnia becomes first country to repeal a cycle helmet law. BikeBiz. 2017 March [cited 2017 August 21]. Available from: http://www.bikebiz.com/news/read/bosnia-becomes-first-country-to-repeal-a-cycle-helmet-law/020827.

Reljic T. Bicycle helmet use to become optional under new legislation. Malta Today. 2018 15 January [cited 2018 February 6]. Available from: http://www.maltatoday.com.mt/news/national/83873/bicycle_helmet_use_to_become_optional_under_new_legislation.

Rissel C, Wen LM. The possible effect on frequency of cycling if mandatory bicycle helmet legislation was repealed in Sydney, Australia: a cross sectional survey. *Health Promot J Austr* 2011;22:178-83.

Rissel C, Wen LM. Response to Rissel and Wen:'The possible effect on frequency of cycling if mandatory bicycle helmet legislation was repealed in Sydney, Australia: a cross sectional survey'reply. *Health Promot J Austr* 2012;23:178-183.

Rizzi M, Stigson H, Krafft M. Cyclist injuries leading to permanent medical impairment in Sweden and the effect of bicycle helmets. *Proceedings of the International Research Council on Biomechanics of Injury (IRCOBI) Conference*. Gothenburg, Sweden 2013; 412-423.

Rojas-Rueda D, Cole-Hunter T, Nieuwenhuijsen M. Ley para el uso obligatorio de casco por ciclistas en zonas urbanas:¿ es bueno para la salud pública?. *Gac Sanit* 2013;27:282.

Robinson DL. Head injuries and bicycle helmet laws. *Accid Anal Prev* 1996;28:463–475.

Robinson DL. Cyclists should wear helmets: Australian laws making helmets compulsory deterred people from cycling. *BMJ* 1997;314:69.

Robinson DL. Helmet laws and health. *Inj Prev* 1998;4:170-2.

Robinson DL. Helmet laws and cycle use. *Inj Prev* 2003;9:380-1.

Robinson DL. Safety in numbers in Australia: more walkers and bicyclists, safer walking and bicycling. *Health Promot J Austr* 2005;16:47-51.

Robinson DL. Do enforced bicycle helmet laws improve public health? *BMJ* 2006;332:722–722.

Robinson DL. Bicycle helmet legislation: Can we reach a consensus? *Accid Anal Prev* 2007;39:86–93.

Rojas-Rueda D, Cole-Hunter T, Nieuwenhuijsen M. Ley para el uso obligatorio de casco por ciclistas en zonas urbanas. ¿Es bueno para la salud pública? *Gac Sanit* 2013;27:282–285.

Salon D, McIntyre A. Determinants of pedestrian and bicyclist crash severity by party at fault in San Francisco, CA. *Accid Anal Prev* 2018;110:149-60.

Sandblom E. What happens when you mandate helmet-wearing among young Swedish cyclists? European Cyclist’s Federation 2015. Available from: https://ecf.com/news-and-events/news/what-happens-when-you-mandate-helmet-wearing-among-young-swedish-cyclists.

Saunders LE, Green JM, Petticrew MP, Steinbach R, Roberts H. What are the health benefits of active travel? A systematic review of trials and cohort studies. *PLOS One* 2013;8:e69912.

Schepers P, Stipdonk H, Methorst R, Olivier J. Bicycle fatalities: trends in crashes with and without motor vehicles in The Netherlands. *Transport Res F* 2017;46:491-499.

Schleinitz K, Petzoldt, T, Gehlert, T. Risk compensation? – The relationship between helmet use and cycling speed under naturalistic conditions. 6th Annual International Cycling Safety Conference. 2017, Davis, California, USA.

Sethi M, Heyer JH, Wall S, DiMaggio C, Shinseki M, Slaughter D, Frangos SC. Alcohol use by urban bicyclists is associated with more severe injury, greater hospital resource use, and higher mortality. *Alcohol* 2016;53:1-7.

Shield J. Minerva, have you led us astray? *Inj Prev* 1997;3:211.

Sieg G. Costs and benefits of a bicycle helmet law for Germany. *Transportation* 2016;43:935-949.

Smith N, Milthorpe F. An observational survey of law compliance and helmet wearing by bicyclists in New South Wales – 1993. NSW Roads and Traffic Authority, Rosebery, NSW. 1993.

Smith NC, Milthorpe FW. Bicycle helmet wearing in New South Wales after legislative mandate. InAustralian Pedestrian and Bicyclist Safety and Travel Workshop, 1994, Melbourne, Australia. 1994.

Spaite DW, Criss EA, Weist DJ, Valenzuela TD, Judkins D, Meislin HW. A prospective investigation of the impact of alcohol consumption on helmet use, injury severity, medical resource utilization, and health care costs in bicycle-related trauma. *J Trauma* 1995;38:287-90.

Stamatiadis N, Deacon JA. Quasi-induced exposure: methodology and insight. *Accid Anal Prev* 1997;29:37-52.

Stigson H, Rizzi M, Ydenius A, Engström E, Kullgren A. Consumer testing of bicycle helmets. 2017 IRCOBI Conference Proceedings–International Research Council on the Biomechanics of Injury. 2017;173-181.

Suelves JM, Cabezas C. Bicicleta y salud: el casco no es el problema, sino parte de la solución [Bicycling and health: the helmet is not the problem but part of the solution]. *Gac Sanit* 2013;27:564.

Sundfør HB, Fyhri A, Phillips RO, Weber C. Still no risk compensation for bicycle helmets - results from an experiment of cycling speed and short term effects of habituation. Proceedings of International Cycling Safety Conference 2015, 15-16 September 2015. Hannover, Germany. 2015.

Swedish Government. 2004. Bill 2003/04:160: Continued work for safe road traffic. Available from https://data.riksdagen.se/fil/6DA81BBC-699B-4B2F-B572-8B078278C61B%202004

SWOV (Institute for Road Safety Research). Face sheet: Bicycle helmets. 2012 [cited 2018 February 7]. Available from: https://www.swov.nl/rapport/Factsheets/UK/FS_Bicycle_helmets.pdf.

SWOV (Institute for Road Safety Research). Mobility on Dutch roads. 2013 [cited 2018 February 8]. Available from: https://www.swov.nl/sites/default/files/publicaties/gearchiveerde-factsheet/uk/fs_mobility_archived.pdf

Thompson DC, Rivara FP, Thompson R. Helmets for preventing head and facial injuries in bicyclists. *Cochrane Database of Systematic Reviews* 1999;CD001855.

Thompson DC, Thompson RS, Rivara FP (a). Risk compensation theory should be subject to systematic reviews of the scientific evidence. *Inj Prev* 2001;7:86–88.

Thompson DC, Thompson RS, Rivara FP (b). Risk compensation theory should be subject to systematic reviews of the scientific evidence. *Inj Prev* 2001;7:88.

Tin Tin S, Woodward A, Thornley S, Ameratunga S. Cycling and walking to work in New Zealand, 1991-2006: regional and individual differences, and pointers to effective interventions. *Int J Behav Nutr Phys Act* 2009;6:64.

Turner L. Australia's helmet law disaster. *Inst Public Affairs Rev* 2012;64:28-29.

Unwin NC. Cycle helmets--when is legislation justified? *J Med Ethics* 1996;22:41-45.

van der Ploeg HP, Merom D, Corpuz G, Bauman AE. Trends in Australian children traveling to school 1971-2003: Burning petrol or carbohydrates. *Prev Med* 2008;46:60-62.

van Zyl R. Bicycle helmet wearing in the Northern Territory. Road safety council of the Northern Territory. 1993 May.

Vulcan AP, Cameron MH, Watson WL. Mandatory bicycle helmet use: experience in Victoria, Australia. *World J Surg* 1992;16:389-97.

Walker I. Drivers overtaking bicyclists: Objective data on the effects of riding position, helmet use, vehicle type and apparent gender. *Accid Anal Prev* 2007;39:417-425.

Walker MB. Law compliance and helmet use among cyclists in New South Wales, December 1990. For the NSW Roads and Traffic Authority, Road Safety Bureau Consultant Report CR 60/90. 1990.

Walker MB. Law compliance and helmet use among cyclists in New South Wales, April 1991. For the NSW Roads and Traffic Authority, Road Safety Bureau Consultant Report CR 1/91. 1991.

Walker MB. Law compliance and helmet use among cyclists in New South Wales, April 1992; A third survey. For the NSW Roads and Traffic Authority, Road Safety Bureau Consultant Report.1992.

Walter SR, Olivier J, Churches T, Grzebieta R. The impact of compulsory cycle helmet legislation on cyclist head injuries in New South Wales, Australia. *Accid Anal Prev* 2011;43(6):2064-2071.

Walter SR, Olivier J, Churches T, Grzebieta R. The impact of compulsory cycle helmet legislation on cyclist head injuries in New South Wales, Australia: A response. *Accid Anal Prev* 2013;52:204-209.

Wang J, Olivier J, Grzebieta R. Response to 'Evaluation of New Zealand's bicycle helmet law' article. *NZ Med J* 2014;14;127:106-108.

Wardlaw M. Do helmets deter cyclists? *Significance* 2006;3:92–93.

Washington S, Haworth N, Schramm A. Relationships between self-reported bicycling injuries and perceived risk of cyclists in Queensland, Australia. *Transp Res Record* 2012:57-65.

Waterston T. Cyclist should wear helmets: Increasing the number of cyclists is more important. *BMJ* 1997;314:69.

Watkins SJ, Mindell J. Doubts about the BMA's policy on bicycle helmets. *BMJ* 2013;347:f4340.

Webman R, Dultz LA, Simon RJ, Todd SR, Slaughter D, Jacko S, Bholat O, Wall S, Wilson C, Levine DA, Roe M. Helmet use is associated with safer bicycling behaviors and reduced hospital resource use following injury. *J Trauma Acute Care Surg* 2013;75:877-881.

YouGov. Britons want helmet law, 2012. [cited 16 February 2018] Available from: https://yougov.co.uk/news/2012/08/09/britons-want-helmet-law/

YouGov. No to Nanny State, except while driving, 2013. [cited 16 February 2018] Available from: https://today.yougov.com/news/2013/06/21/no-no-nanny-state-except-while-driving/

Zibung E, Riddez L, Nordenvall C. Helmet use in bicycle trauma patients: a population-based study. *Eur J Trauma Emerg Surg* 2015;41:517–521.

Appendix A: Study protocol for the systematic review of the impact of bicycle helmet legislation on cycling exposure

This study aimed to answer the question of “Does bicycle helmet legislation deter cycling?”

All research questions were addressed through systematic reviews of the peer-reviewed and grey literature.

Bicycle helmet legislation (BHL)

BHL exists in Argentina, Australia, Austria, parts of Canada, Chile, Croatia, Czech Republic, Estonia, Finland, France, Iceland, Israel, Japan, Jersey, Latvia, Lithuania, Malta, Namibia, New Zealand, Nigeria, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, United Arab Emirates and parts of the United States. The exact details of each law (e.g., effective date, age of cyclists, level of enforcement) were identified from government websites and by contacting government representatives or road safety researchers. This information was enhanced by the literature search whenever possible.

The impact of BHL on cycling

The peer-reviewed literature was searched for studies with bicycle helmet content from five research databases (EMBASE, MEDLINE, COMPENDEX, SCOPUS, and WEB OF SCIENCE) on 16 February 2017. The search terms were (helmet* AND (bicycl* OR cycl*)). This strategy was intentionally vague to minimise false negatives (i.e., not identifying relevant studies). In relation to EMBASE and MEDLINE, the subject headings for “helmet” and “bicycling” were used. The search was performed independently by two researchers who then removed duplicate records. The resulting master list of articles was screened by their titles/abstracts against the inclusion criteria. Disagreements between the two reviewers were discussed until a consensus was reached with a third person adjudicating unresolved issues. Specific details regarding the search and the number of records found are given in Tables A.1. Details related to systematic inclusion of studies in the current review are also given in Table A.2.

Table A.1. Number of articles identified through original search for the systematic review of the impact of BHL on cycling (16 February 2017)

Compendex	Search Terms	Records
1.	cycl* OR bicycl*, all fields	933123
2.	helmet*, all fields	6625
3.	1. AND 2.	409
Embase		
1.	"bicycle" subject heading, include all subheadings	8623
2.	"helmet" subject heading, include all subheadings	5240
3.	1. AND 2.	948
Medline	Search Terms	Records
1.	"bicycling" subject heading, include all subheadings	9424
2.	"head protective devices" subject heading, include all subheadings	2998
3.	1. AND 2.	814
Scopus	Search Terms	Records
1.	cycl* OR bicycl*, title	622562
2.	helmet*, title	3750
3.	1. AND 2.	690
Web of Science	Search terms	Records
1.	cycl* OR bicycl*, title	653118
2.	helmet*, title	3235
3.	1. AND 2.	580

Table A.2. Summary of Articles Screened for the systematic review of the impact of BHL on cycling

	Records
Records identified through database searching	3441
Duplicates removed	1832
Records after duplicates removed	1609
Records identified through other sources	36
Records screened	1645
Records excluded	1556
Full-text articles assessed for eligibility	89
Full-text articles excluded, with reasons	55
Studies included in qualitative synthesis	34
Studies included in quantitative synthesis	

Articles were excluded if they: a) were not a primary study or systematic review (i.e., commentaries were included for a full-text review; however, any relevant data was extracted from the source material); b) did not include an appropriate comparison group; and c) did not appropriately measure the effects of BHL or had weak external validity (e.g., simulated laboratory studies that were not conducted in the real world were included for a full-text review but not included as source material).

An ideal study included several observations of cycling participation and cycling distance in both pre- and post-BHL periods from a representative sample. Elements of studies that were considered poor were the use of convenience sampling, proxy measures for cycling participation, studies that estimate existing trends from three or fewer time points, or there was a large time gap between observations.

The grey literature was identified by contacting road safety organisations in countries with existing BHL. International conference proceedings were also searched such as the Transport Research Board Annual Meeting, the World Conference on Injury Prevention and Safety Promotion, and the International Cycling Safety Conference. Websites sponsored by anti-helmet organisations such as the Bicycle Helmet Research Foundation were searched for relevant data. A Google Scholar search using the above terms netted over 15,600 results. This was an unreasonably large number of articles to screen, although only the first 100 pages of results (1000 records) were viewable. An additional Google search was performed, limiting the results to .gov, .org, and .edu domains only. Other platforms (e.g., Trove and Worldcat) and datasets (e.g., ProQuest which is a repository for dissertations and theses) were searched for grey literature.

Studies that met inclusion criteria were read in full by two researchers and relevant data was extracted. The references contained in these articles were screened against inclusion criteria and relevant studies were added accordingly. The systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The included studies were summarised based on their jurisdiction in which the study was conducted, the design of the studies, and their findings and results. A summary of the articles is provided in Table 3.7 in Chapter 3.

A meta-analysis was not possible as there was no single measure unifying all studies. For example, changes in counts of cyclists from helmet use studies is not equivalent to changes in proportions of cycling amounts (e.g., cycled in the past week, past 3 months, past six months or later/never). Therefore, studies were synthesised qualitatively with a descriptive analysis of common themes across studies.

Appendix B: Systematic Review of bicycle helmets and behavioural factors such as risk compensation

The aim of this project was related to the following research question:

“Is helmet wearing associated with behavioural factors? Specifically, does helmet wearing increase the likelihood of a) cyclists’ risky behaviour and/or b) disobeying traffic laws?”

Risk taking (or risky behaviour) was considered as either a risky behaviour with a potentially negative outcome in which precautions are not taken, such as speeding (i.e., exceeding posted speed limit), or disobeying traffic laws, such as wrong way riding, disobeying stop signs (e.g., not stopping at an intersection), or disobeying traffic signals (e.g., running a red light).

This research question was addressed through a systematic review of the peer-reviewed literature. The peer-reviewed literature was searched on 17 May 2017 for studies with bicycle helmet content from five research databases (EMBASE, MEDLINE, COMPENDEX, SCOPUS, and WEB OF SCIENCE). The search terms were approximately (bicycl* OR cycl*) AND (helmet*) AND (risk*). In relation to EMBASE, the subject headings for “bicycle”, “helmet”, and “high risk behavior” were used. In relation to MEDLINE, the subject headings for “bicycling”, “head protective devices”, and “risk taking” were used. The search was performed independently by two researchers who then removed duplicate records. The resulting master list of articles was screened by their titles/abstracts against inclusion criteria. Disagreements between the two reviewers were discussed until a consensus was reached or adjudicated by a third author. Specific details regarding the search and the number of records found are given in Table B.1. Details of the inclusion process are also given in Table B.2.

In this systematic review, studies were categorised in one of the following four groups:

1) Commentaries

2) Systematic reviews of previous studies

3) Computer simulations and lab studies

4) Epidemiological studies

    a. Cohort or case-control studies

    b. Randomised control trials or randomised crossover trials

    c. Crash data

To be included in the current systematic review, articles had to be a primary study which uses first instance data. Studies that report data on the effect of helmet wearing on risky behaviour and disobeying traffic laws were included for a qualitative synthesis.

Table B.1. Number of articles identified through original search (17 May 2017)

Embase	Search Terms	Records
1.	“bicycle” subject heading, include all subheadings	7128
2.	“helmet” subject heading, include all subheadings	4679
3.	“high risk behavior” subject heading, include all subheadings	21136
4.	1. AND 2. AND 3.	21
Medline	Search Terms	Records
1.	“bicycling” subject heading, include all subheadings	9742
2.	“head protective devices” subject heading, include all subheadings	3101
3.	“risk taking” subject heading, include all subheadings	23764
4.	1. AND 2. AND 3.	24
Compendex	Search Terms	Records
1.	cycl* OR bicycl*, all fields	949739
2.	helmet*, all fields	6847
3.	risk*, all fields	364982
4.	1. AND 2. AND 3.	97
Scopus	Search Terms	Records
1.	cycl* OR bicycl*, title	628884
2.	helmet*, title	3794
3.	risk*, title	574415
4.	1. AND 2. AND 3.	27
Web of Science	Search terms	Records
1.	cycl* OR bicycl*, title	660915
2.	helmet*, title	3300
3.	risk*, title	586143
4.	1. AND 2. AND 3.	21

Table B.2. Summary of Articles Screened for the systematic review of the association between BHL and risk compensation

	Records
Records identified through database searching	190
Duplicates removed	9
Records after duplicates removed	141
Records identified through other sources	3
Records screened	144
Records excluded	105
Full-text articles assessed for eligibility	39
Full-text articles excluded, with reasons	17
Studies included in qualitative synthesis	22
Studies included in quantitative synthesis	

Out of the four categories of studies, commentaries were included for a full-text review; however, any relevant data were extracted from the source material. Systematic reviews of previous studies were independently read (not included) by the two reviewers to find relevant studies. Computer simulations and lab studies, and epidemiological studies (i.e., cohort studies, case-control studies, randomised control trials, randomised crossover trials, and crash data) were included in this systematic review.

Studies that meet inclusion criteria were read in full by two researchers and relevant data was extracted. The references contained in these articles were screened against inclusion criteria and relevant studies were added accordingly. The systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.

The included studies were summarised and evaluated against the level of evidence afforded by their sample, study design, and interpretation of results. The two researchers separately provided comments for each included study. A summary of the included article is provided in Table 4.1 in Chapter 4.

An ideal study, for example, would include data from actual crashes in the real world or data extracted from the real world with a randomised sample (i.e., randomised control trials and randomised crossover trials). Commentaries are the poorest studies and were included for a full-text review; however, any relevant data was extracted from the source material. Elements of studies that were also considered poor are the lack of a control group, the use of convenience sampling, and proxy measures for risk taking.

In the current systematic review, a single measure was not reported for all included studies, therefore, meta-analyses were not performed and only a qualitative assessment of helmet use and behavioural factors was performed.