

RESEARCH

Helmet legislation and admissions to hospital for cycling related head injuries in Canadian provinces and territories: interrupted time series analysis

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Abstract

Objective To investigate the association between helmet legislation and admissions to hospital for cycling related head injuries among young people and adults in Canada.

Design Interrupted time series analysis using data from the National Trauma Registry Minimum Data Set.

Setting Canadian provinces and territories; between 1994 and 2003, six of 10 provinces implemented helmet legislation.

Participants All admissions (n=66 716) to acute care hospitals in Canada owing to cycling related injury between 1994 and 2008.

Main outcome measure Rate of admissions to hospital for cycling related head injuries before and after the implementation of provincial helmet legislation.

Results Between 1994 and 2008, 66 716 hospital admissions were for cycling related injuries in Canada. Between 1994 and 2003, the rate of head injuries among young people decreased by 54.0% (95% confidence interval 48.2% to 59.8%) in provinces with helmet legislation compared with 33.1% (23.3% to 42.9%) in provinces and territories without legislation. Among adults, the rate of head injuries decreased by 26.0% (16.0% to 36.3%) in provinces with legislation but remained constant in provinces and territories without legislation. After taking baseline trends into consideration, however, we were unable to detect an independent effect of legislation on the rate of hospital admissions for cycling related head injuries.

Conclusions Reductions in the rates of admissions to hospital for cycling related head injuries were greater in provinces with helmet legislation,

but injury rates were already decreasing before the implementation of legislation and the rate of decline was not appreciably altered on introduction of legislation. While helmets reduce the risk of head injuries and we encourage their use, in the Canadian context of existing safety campaigns, improvements to the cycling infrastructure, and the passive uptake of helmets, the incremental contribution of provincial helmet legislation to reduce hospital admissions for head injuries seems to have been minimal.

Introduction

Bicyclists are vulnerable road users. Compared with car occupants, bicyclists are more than twice as likely to be fatally injured per person trip and up to 10 times more likely to be injured per kilometre travelled.^{1 2} Moreover, as with many transportation related injuries, cycling injuries are often to the head; such injuries account for approximately 30% of admissions to hospital for cycling related injuries³⁻⁶ and over 75% of cycling fatalities.^{7 8} A proportion of these injuries can be prevented by the use of helmets,⁹⁻¹² and legislation mandating helmet use for all cyclists, or for cyclists under a given age (for example, 18 years), has been implemented in six of 10 Canadian provinces and countries such as Australia, New Zealand, and parts of the United States. Such laws, however, are contentious and the focus of active public debate.^{13 14}

Fuelling the debate is the uncertain effectiveness of legislation to reduce head injuries. Several studies have attempted to answer this fundamental question but have been limited by sample size

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ICD-9 and ICD-10 codes used to identify admissions to hospital for cycling related injuries

Captions for supplementary figures 1-3

Rate ratio estimation from segmented regression analysis

Supplementary figures 1-3

or methodological quality.¹⁵⁻²⁰ Controlled before and after studies do suggest a protective effect of legislation targeting young bicyclists,²¹⁻²⁴ but only one of these studies, which examined cycling related deaths, accounted for baseline trends in cycling injury rates.²² Moreover, no controlled before and after study has investigated the association between helmet legislation and head injuries in adult cyclists. We therefore examined changes in the rate of cycling related head injuries associated with helmet legislation in young people and adults while accounting for baseline trends in the rate of cycling injuries.

Methods

We used a controlled, interrupted time series design—a series of observations taken at regular, evenly spaced intervals, before and after the implementation of an intervention, in both intervention and control groups. This design accounts for baseline trends and is among the strongest of quasi-experimental approaches for evaluating the effect of an intervention.²⁵

Data sources and variable definitions

We analysed annual counts of admissions to hospital for cycling related injuries obtained from the National Trauma Registry Minimum Data Set, managed by the Canadian Institute for Health Information. The registry contains personal and diagnostic information on all admissions to acute care hospitals in Canada due to injury from 1994 onwards. The cause and nature of each patient's injuries are coded according to the international classification of diseases (ICD-9, ICD-9-CM, and ICD-10-CA), and up to 25 injuries are coded per patient. We included admissions to hospital due to a cycling injury that occurred in the 15 years between 1 April 1994 and 31 March 2008 (see supplementary table 1 for cycling injury codes) and we summed counts by fiscal year—for example, fiscal year 1994 runs from 1 April 1994 to 31 March 1995. The national trauma registry does not include information on helmet use.

We defined head injured cyclists as those with an injury to the brain, skull, scalp, or face (see supplementary table 2 for head injury codes). We also included the total number of admissions to hospital for cycling related injuries (that is, admissions due to a cycling injury to any body region, including the head) in our analysis to control for trends in admissions to hospital for cycling related head injuries that were attributable to factors other than helmet legislation.

Canada includes 10 provinces and three territories. Between 1994 and 2003, helmet laws were introduced in six provinces, and these provinces comprised the intervention group (table 1). Although adults are not specifically targeted by legislation in two of these provinces, a strong modifying effect of legislation aimed at young people on helmet use in adults in these provinces has been previously observed²⁶ and so we grouped these provinces with the other intervention provinces. The four provinces and three territories that did not implement helmet legislation comprised the control group. We considered the year in which provincial legislation was enacted to be the time point at which the intervention occurred; all years thereafter were considered post-intervention. In Ontario and New Brunswick, where legislation was enacted after the Canadian cycling season (after September), we considered the intervention to have occurred in the subsequent year. We defined young people as those aged less than 18 years.

Statistical analyses

We used two methods to assess the association between helmet legislation and cycling related head injuries. Firstly, we calculated the annual rates of admissions to hospital for cycling related head injuries per 100 000 person years in all provinces and in the territories. Population counts for the denominator were obtained from CANSIM (Canadian Socioeconomic Information Management System).²⁷ Sparse injury counts among young people in the territories and in smaller provinces necessitated the estimation of crude rates for young people, whereas among adults we estimated age adjusted rates using three age strata (18-24 years, 25-44 years, and ≥ 45 years) and the 2006 Canadian population as the standard population. We then estimated the percentage change in rates in the legislation group between 1994 and 2003 (the time over which legislation was implemented in these provinces), and we compared this change with the percentage change in the rates in the control group over this same period. We followed these same steps in the analysis of total admissions to hospital for cycling related injuries.

Secondly, using an over-dispersed Poisson segmented regression analysis, we modeled the annual rates of admissions to hospital for cycling related head injuries per total admissions to hospital for cycling related injuries—that is, using a different denominator than in the first analysis. Segmented regression is a statistical method used specifically for assessing the response to an intervention while controlling for baseline trends in interrupted time series studies (for more information see supplementary appendix 1).²⁵⁻²⁸ We included all available data from 1994 to 2008, specified separate models for young people and adults in each intervention province (12 models in total), and included interaction terms in each model to model the rate in the control group (see supplementary appendix 1 for model formulation).

Results of the segmented regression analysis were expressed in two ways. Firstly, we expressed the effect of legislation one year after its implementation within each intervention province as a rate ratio and its 95% confidence interval, with rate ratios < 1 suggesting that the rate of head injuries one year after implementation of the legislation was less than if legislation had not been implemented—that is, that legislation was effective. Although we assessed the effect of legislation at only one time point (one year after its implementation), all time points contributed to model parameterisation and estimation of rate ratios. Thus, we averaged out seasonal or other variation in the injury rate in the year after the introduction of the legislation. The second way in which results of the segmented regression analysis were expressed was through the statistical significance of the interaction terms that compared the post-legislation changes in the rate of head injuries in the intervention province with those in the control group. All tests of statistical significance reflect a two sided α of 0.05. Since error terms of consecutive observations may be correlated in a time series, we visually inspected plots of model residuals against time to ensure that no pattern suggesting autocorrelation was evident. We estimated the summary estimates of the effect of helmet legislation among young people and adults by combining individual rate ratios in a random effects model. All analyses were conducted with SAS 9.2.

Results

Between 1994 and 2008 we identified 66 716 admissions to hospital for cycling related injuries across the Canadian provinces and territories (table 2). Head injuries accounted for

29.6% of these, and over two thirds of head injured cyclists had a brain injury. Overall, 19% of head injured cyclists had a face injury without a concomitant scalp, skull, or brain injury. Cyclists aged less than 18 years comprised 44.7% (n=29 844) of admissions to hospital for injuries and 52.6% (n=10 369) of admissions for head injuries, despite comprising approximately 20% of the Canadian population. The majority of injuries occurred in males (75.0%, n=50 004). Approximately 1% of admissions for head injuries were fatal compared with 0.4% of all admissions for injuries.

The rate of hospital admissions for cycling related head injuries in Canada among young people decreased from 17.0 to 4.9 per 100 000 person years between 1994 and 2008 (fig 1). In provinces that implemented helmet legislation, the rate decreased steeply between 1994 and 2003, the time over which legislation was implemented, from 15.9 to 7.3 per 100 000 person years, corresponding to a 54.0% (95% confidence interval 48.2% to 59.8%) reduction. In provinces and territories that did not implement helmet legislation, the rate of admissions for cycling related head injuries also decreased between 1994 and 2003, but to a lesser degree. The reduction in provinces without legislation was 33.2% (23.3% to 43.0%), corresponding to a decrease from 19.1 to 12.9 per 100 000 person years. Among adults, the rate of admissions for cycling related head injuries was low in all provinces and across all study years. Between 1994 and 2003, the rate of head injuries in adults in provinces with helmet legislation decreased by 26.2% (16.0% to 36.3%), a reduction from 3.0 to 2.2 per 100 000 person years, compared with a negligible increase in rates in provinces and territories with no legislation, from 2.7 to 2.8 per 100 000 person years.

The rate of total hospital admissions for cycling related injuries also decreased across Canada among young people but not among adults between 1994 and 2008 (see supplementary figure 1). Between 1994 and 2003, the rate among young people decreased to a similar extent in provinces both with legislation (28.0%, 95% confidence interval 22.8% to 33.2%) and without legislation (22.3%, 15.0% to 29.6%), suggesting fewer young cyclists, improvements to cycling safety, or a change in hospital admission policies. Among adults the rate of total hospital admissions for cycling related injuries increased between 1994 and 2003, but this increase, from 10.0 to 10.5 per 100 000 person years in provinces that implemented helmet legislation, and from 9.7 to 10.0 per 100 000 person years in provinces and territories with no such legislation, was not statistically significant in either group.

Using segmented regression analysis, we did not detect a statistically significant effect of helmet legislation on the rate of hospital admissions for cycling related head injuries per total admissions for cycling related injuries among young people in the year after legislation was implemented (fig 2). The age group of cyclists targeted by legislation (<18 years versus all ages) was not associated with meaningful changes in rate ratios for head injuries (fig 2). The rate ratio was statistically significant (indicating a protective effect of legislation) in only one province, New Brunswick, where legislation applies to all cyclists (fig 2). None of the interaction terms were statistically significant, indicating no difference in the post-legislation rate of head injuries in provinces with legislation compared with those without legislation. Among adults, a statistically significant protective effect of helmet legislation was detected in one province, British Columbia, where legislation applies to all cyclists (fig 3). None of the interaction terms were significant. Results did not change appreciably when face injuries were excluded from the definition of head injuries (see supplementary figures 2 and 3).

Discussion

Since 1994 in Canada the rate of bicycling injuries, including those to the head, has decreased among young people. In six provinces where helmet legislation was implemented, we observed a steep decline in the rate of hospital admissions for young people with cycling related head injuries (54% reduction) compared with provinces and territories without legislation (33% reduction). In adults over this same period we observed a 26% reduction in the rate of admissions for head injuries in provinces that implemented helmet legislation, compared with no reduction in provinces without legislation. While these results superficially suggest an important effect of legislation, after taking baseline trends into consideration we were unable to show an independent effect of helmet legislation on the rate of head injuries per hospital admission for a cycling related injury one year after the implementation of legislation, either overall or according to the age group of cyclists targeted by the legislation.

Three previous studies have investigated the effects of helmet legislation on bicycle related head injuries using a before and after design and a concurrent comparison group.^{21 23 29} All focused on paediatric populations. In a Canadian study that analysed data from the National Trauma Registry Minimum Data Set (years 1994 to 1997), the same data source used in our study, the authors concluded that helmet legislation was associated with a significant reduction in the rate of cycling related head injuries among Canadians aged 5-19 years.²¹ Using the same data source but with an extended period of follow-up, over which time two additional provinces implemented legislation, we replicated the results of this previous study in our initial analysis that did not adjust for baseline trends. In our time series analysis, we none the less could not confirm that the reduction in the rate of head injuries was an independent effect of helmet legislation above and beyond the concomitant declining trend in the rate of head injuries observed throughout Canada.

Helmets reduce the risk of injuries to the brain by up to 88%, the head by up to 85%, and the face by up to 65%.¹⁰⁻¹² Laws that mandate the use of helmets increase the chance that cyclists will wear a helmet, especially when they apply to all cyclists.^{26 30} Given this evidence, why is it difficult to detect a decrease in hospital admissions for cycling related head injuries after the implementation of helmet legislation? Concurrent interventions that improve cycling safety combined with municipality specific helmet legislation are two possible explanations. The Canadian Cycling Association's CAN-BIKE programme to promote cycling safety, for example, has been taught in Canada since 1985,³¹ and local educational programmes, media campaigns, and subsidised or free helmet distribution programmes are also known to have occurred in Canada around the time legislation was implemented (table 1).³²⁻³⁷ Similarly, changes to cycling infrastructure over the study period (for example, traffic calming, and designated bicycle lanes and routes)³⁸⁻⁴¹ could have confounded associations with helmet legislation. In provinces and territories without legislation, several municipalities implemented helmet legislation between 1994 and 2003.^{42 43} Notably, seven municipalities in Newfoundland and Labrador, including St John's, the province's largest municipality, implemented bylaws that may have contributed to the steep decrease in cycling related head injury rates we observed in this province.⁴⁴

A third possible explanation for our results is that the effectiveness of helmets is greater for mild and moderate head injuries than for the severe head injuries captured by hospital

admission data. Diagnostic and prognostic improvements over time that allowed for the treatment of patients with mild and moderate head injuries in emergency rooms, as opposed to inpatient hospital wards, could have further impeded our ability to detect an effect of helmet legislation, if one exists.^{45 46}

While minimal enforcement may compromise the effectiveness of helmet legislation, fear of the police and of fines motivates helmet use,⁴⁷ and despite nominal fines and few issued tickets, helmet use rose dramatically in provinces immediately after the enactment of legislation (table 1).³⁰

Strengths and limitations of this study

The National Trauma Registry Minimum Data Set captures information on all hospital admissions for cycling related injuries in Canada. Cyclists who die from their injuries before reaching a hospital are not included. Additional data on emergency room visits would have been beneficial, both to make inferences on the association between helmet legislation and milder head injuries and to refine counts of head injuries in small provinces and in the territories. None the less, before 2002 no province or territory systematically reported data on visits to emergency rooms to a national database. The National Trauma Registry Minimum Data Set also makes no distinction between cyclists injured on-road and off-road (for example, while jumping on BMX bikes or mountain biking), yet provincial helmet laws apply only to on-road cyclists. Helmets are standard in off-road cycling, with usage more than 80% in the 1990s and nearly 100% in recent studies.⁴⁸⁻⁵⁰ This increase, coupled with improvements to helmet design, may have contributed to a reduction in bicycle related head injuries in provinces where off-road cycling is common (British Columbia, Alberta, Quebec).

Data on exposure to cycling are desirable, yet were unavailable for Canada at the time helmet legislation was implemented. Recent data from the Canadian Community Health Survey indicate that bicycle use varies across provinces,²⁶ reflecting differences in climate and cycling infrastructure. Variation in cycling possibly contributes to differences in cycling injury rates between provinces. Within a province, however, the introduction of helmet legislation does not discourage bicycle use and thus permits assessment of helmet legislation on cycling related head injuries.^{26 51}

One further limitation of our study is the small number of time points, especially preintervention, which may have reduced the power of the segmented regression analysis.^{25 28 52} In small provinces, few observations at each time point resulted in wide confidence intervals.

Strengths of our study include the number of provinces, territories, and years analysed, combined with our use of descriptive statistics and statistical methods for interrupted time series data that explicitly considered baseline trends. This is the first study to use a controlled before and after design to assess the association between helmet legislation and cycling related head injuries in adults, as well as the first controlled study to incorporate background trends in rates of injury. Results from our study are timely and relevant, following ongoing debates in the lay and medical press as to the merit of bicycle helmet laws.⁵³⁻⁵⁶

Conclusion

From 1994 to 2008, we observed a substantial and consistent decrease in the rate of hospital admissions for cycling related head injuries across Canada. Reductions were greatest in provinces with helmet legislation. Rates of admissions for head

injuries, however, were decreasing before the implementation of provincial helmet legislation and did not seem to change in response to legislation. While helmets reduce head injuries and their use should be encouraged, this study suggests that, in the Canadian context of provincial and municipal safety campaigns, improvements to the cycling infrastructure, and the passive uptake of helmets, the incremental contribution of provincial helmet legislation to reduce the number of hospital admissions for head injuries is uncertain to some extent, but seems to have been minimal.

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Contributors: JD, TR, and RZ conceived and designed the study. JD analysed the data and all authors contributed to its interpretation. JD drafted the manuscript and all authors participated in the revision process and have approved this submission for publication. JD and RZ had full access to all of the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

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Ethical approval: Not required.

Data sharing: Cycling injury counts by province and year are available from the corresponding author at jessica.dennis@mail.utoronto.ca.

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What is already known on this topic

Cyclists are vulnerable road users; head injuries among cyclists account for 75% of cycling related fatalities

Debate exists about whether or not helmet legislation is an effective strategy to reduce serious head injuries among child and adult cyclists

What this study adds

When baseline trends in cycling related injury rates were considered, the overall rates of head injuries were not appreciably altered by helmet legislation

In the context of provincial and municipal safety campaigns, improvements to the cycling infrastructure, and the passive uptake of helmets, the incremental benefit of provincial helmet legislation to reduce admissions to hospital for head injuries is substantially uncertain

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Tables

Table 1 | Bicycle helmet legislation in Canadian provinces and territories

Province or territory	Date implemented	Penalty (\$C)	Enforcement	Cointerventions	Helmet use		
					Prelegislation	Post-legislation	2009 (%)*
Legislation applies to all cyclists:							
New Brunswick	December 1995	21	No information available	No information available	No information available	No information available	51
British Columbia	September 1996	100	No information available	Province wide safe cycling promotion programme (education, media, helmet rebate) launched in 1995 ³⁶	47% in 1995 ³⁶	72% in 1999 ³⁶	59
Nova Scotia	July 1997	25 for first offence, 50 for second, 100 for third or subsequent offences	60 tickets issued in 1997, 176 in 1998, and 113 in 1999 ³²	Extensive media campaign promoting law launched two months before its implementation ³²	36% in 1995 ³²	84% in 1999 ³²	66
Prince Edward Island	July 2003	120 or participation in 2 hour safety seminar	3 tickets and multiple warnings issued between 2003 and 2009†	No information available	No information available	No information available	51
Legislation applies to cyclists aged <18 years:							
Ontario	October 1995	60	Minimal enforcement ³⁰	Prelegislation helmet discounts, media campaigns, and targeted school helmet promotion activities ^{30,33}	Young people: 44% in 1994 ³³	Young people: 66% in 1997 ³³	34
Alberta	May 2002	69	16 tickets issued in 2003, 48 in 2004 ³⁷	Public health awareness campaigns and targeted school health activities implemented in 2004 ³⁷	Young people: 28% in 2000, adults: 49% in 2000 ³⁷	Young people: 83% in 2004, adults: 48% in 2004 ³⁷	48
No legislation:							
Manitoba‡	—	—	—	—	—	—	22
Newfoundland and Labrador	—	—	—	—	—	—	38
Saskatchewan	—	—	—	—	—	—	23
Quebec	—	—	—	—	—	—	26
Northwest Territories	—	—	—	—	—	—	28
Yukon	—	—	—	—	—	—	51
Nunavut	—	—	—	—	—	—	—

*Information from: Bicycle helmet use, 2009. Statistics Canada; 2011. www.statcan.gc.ca/pub/82-625-x/2010002/article/11274-eng.htm. Estimates of helmet use in Nunavut were too unreliable to be published.

†Information from: Bike helmet law needs better enforcement, says MLA. CBC News; 2009. www.cbc.ca/news/canada/prince-edward-island/story/2009/05/05/pei-bike-helmet-law.html.

‡Legislation mandating helmet use for cyclists less than 18 years of age was tabled by the Manitoba government 23 May 2012.

Table 2 | Characteristics of cyclists admitted to hospital in Canada, 1 April 1994 to 31 March 2008

Characteristics	Injured cyclists (n=66 716)		Head injured cyclists (n=19 732)	
	No	% (95% CI)	No	% (95% CI)
Type of head injury*:				
Brain	—	—	13 340	67.6 (67.0 to 68.3)
Scalp or skull	—	—	4770	24.2 (23.6 to 24.8)
Face	—	—	7010	35.5 (34.9 to 36.2)
Age (years):				
<18	29 844	44.7 (44.4 to 45.1)	10 369	52.6 (51.9 to 53.3)
18-24	5765	8.6 (8.4 to 8.9)	1847	9.4 (9.0 to 9.8)
25-44	15 217	22.8 (22.5 to 23.1)	3798	19.3 (18.7 to 19.8)
≥45	15 890	23.8 (23.5 to 24.1)	3718	18.8 (18.3 to 19.4)
Males	50 004	75.0 (74.6 to 75.3)	15 249	77.3 (76.7 to 77.9)
Discharge status dead	267	0.4 (0.3 to 0.5)	224	1.1 (1.0 to 1.3)

*Cyclists may have had more than one type of head injury.

Figures

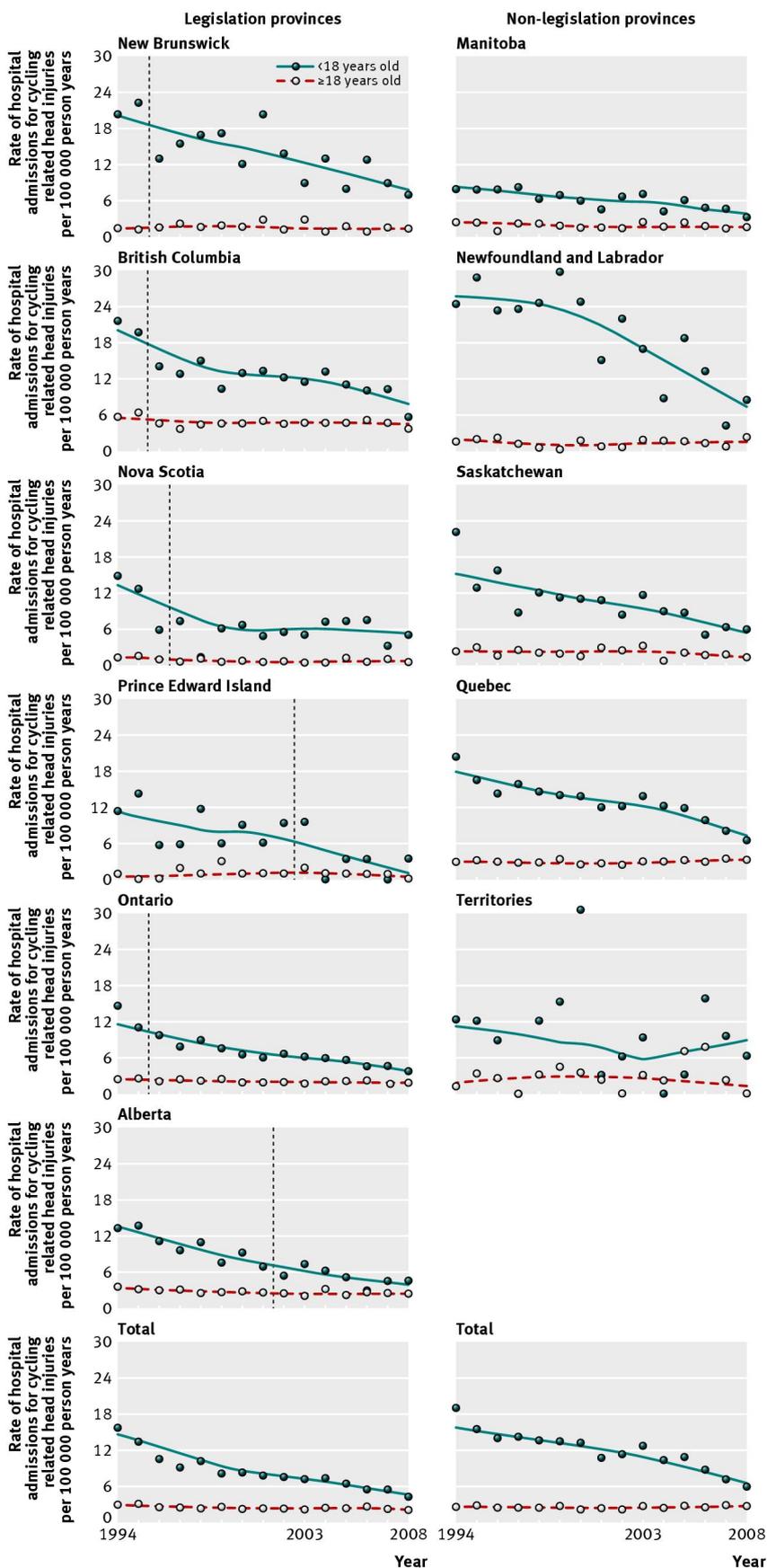


Fig 1 Annual rate of hospital admissions for cycling related head injuries, 1994 to 2008, in Canadian provinces and territories, and in Canadian provinces and territories grouped by bicycle helmet legislation status. Rates are connected by a LOESS regression line. Vertical bars indicate year legislation was enacted. Legislation in Ontario and Alberta targeted only cyclists aged less than 18 years

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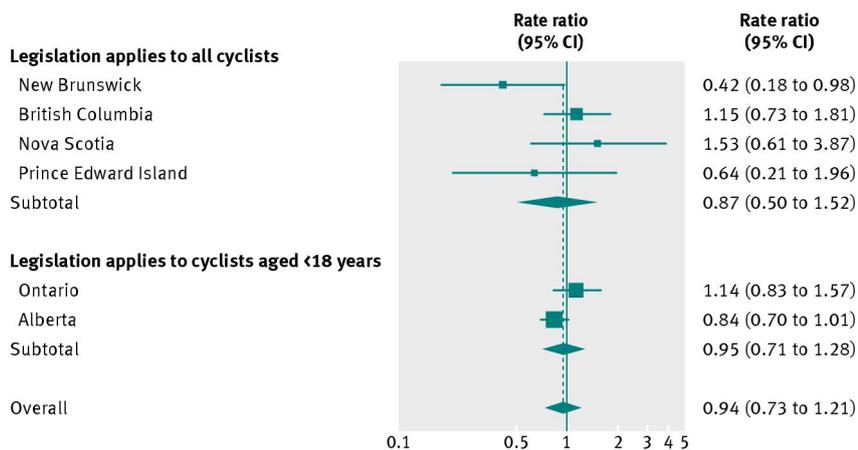


Fig 2 Change in rate of hospital admissions for head injuries per injured cyclist among cyclists aged less than 18 years one year after implementation of bicycle helmet legislation. Rate ratios <1 suggest a protective effect of helmet legislation. The area of the square is proportionate to the weight of each province in the summary estimate

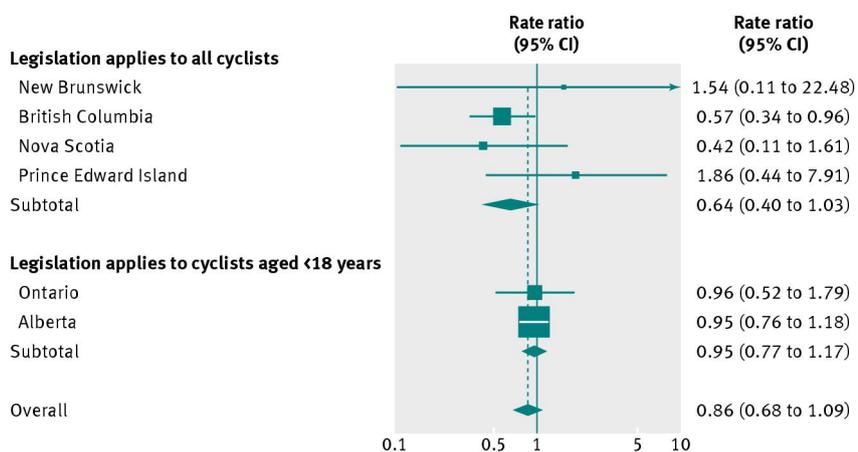


Fig 3 Change in rate of hospital admissions for head injuries per injured cyclist among cyclists aged 18 years and older one year after implementation of bicycle helmet legislation. Rate ratios <1 suggest a protective effect of helmet legislation. The area of the square is proportionate to the weight of each province in the summary estimate

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