Evaluating bicycle helmet use and legislation in Canada

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Between 1995 and 1997, four provinces of Canada introduced helmet legislation either for all cyclists or for those under 18 years of age. Later in 2002, Alberta also enforced helmet legislation for cyclists under 18 years of age. Has helmet legislation provided a benefit and is it the best approach? This paper examines evidence in terms of cycle usage, accidents, health, environment, law enforcement and civil liberties to assess the outcome. Comparing provinces with helmet legislation to provinces without for the period 1994 to 1998 shows a relative net benefit for those without legislation. It appears helmet legislation has not provided the benefits expected, infringes civil liberties and has caused more harm than good.

Background information

Australia introduced helmet legislation across all states from 1990 to 1992 and New Zealand soon followed in 1994. Both provided an inducement for provinces in Canada to consider legislation. Selection and presentation of data from Australia may have given the impression of a benefit due to reduced head injuries cited in some reports [1,2] but this was more likely due to reduced cycling. Reductions in cycling of 36% for New South Wales, 36% for Victoria and 20% for Western Australia have been reported.[3] Clarke[4,5] has provided a full assessment of Australia's helmet laws and reported numerous mistakes made by Australia in assessing helmets and legislation. In 2008, an article in the Health Journal of Australia[6] concluded: “Compulsion to wear a bicycle helmet is detrimental to public health in Australia.” In addition to concerns about helmet legislation reducing cycling, public health and environmental implications, there are concerns about helmet safety issues - i.e. helmet use appears to increase the accident rate plus they may exacerbate rather than offer protection from rotational acceleration of the head.

Method

To evaluate bicycle helmet use and legislation in Canada, a board approach is taken. Are cyclists at a high risk that may warrant helmet legislation? The ***'safety comparison'*** helps to answer this question. The ***'health benefit comparison'*** provides an outline of the benefits of cycling and the possible losses that may result from reduced cycling. The ***'energy comparison'*** indicates the environmental losses that may result from reduced cycling levels or transfer to other modes of travel. The ***'Impact of helmet legislation on cycle use'*** provides an assessment of the available survey data on cycle usage in provinces with legislation. The ***'Cycle use - combined survey indications'*** provides an assessment of the overall reduction in cycling levels in legislative provinces. The ***'Assessing helmet effects on injury for children and youth aged 5-19 years'*** examines the accident data for admissions 1994-98 and adjusts the data for the reduced level of cycling activity in legislative provinces, thereby allowing a comparison with non-legislative provinces based on the level of cycling activity. ***'Comparing results'*** looks at the findings and compares with other results from Australia. ***'Fatality trends for Canada'*** examines the evidence to see if mandatory helmets have contributed to reducing fatalities. ***'Civil liberties'*** considers the results and if legislation is justified or if it infringes civil liberties and the Canadian Charter of Rights and Freedoms. A ***'Summary assessment'*** provides a brief assessment of the outcome from helmet legislation on 'Health', 'Accidents', 'Fatalities', 'Environment', 'Accident Compensation' and 'Law Enforcement'. Finally, after considering all of the aspects, the ***'Conclusions'*** are presented.

Safety comparison
Canada and Australia have similar ratios of road deaths: 87 compared to 86 per million population for 2004.[7] Both are behind the 49 per million population in the Netherlands, which has a very high cycling rate with a low use of helmets. Reports from Australia detail the risk of fatality and hospital admission for head injury per million hours of travel.[8] (see Table 1)

Table 1

Risk of fatality and hospital admission for head injury per million hours of travel.

	Fatality	Hosp/admiss for head injury
Bicyclist	0.41	2.2
Pedestrian	0.80	2.0
Car occupant	0.46	1.6
Motorcyclist	7.50	18.0

The figures show cyclists are not especially at risk compared to other road users. There are difficulties comparing bicyclists to car users and motorcyclists because generally both of the latter are trained adults, whereas bicyclists include children and teenagers. Reported emergency admissions (Cook & Sheikh) at National Health Service hospitals in England for injuries sustained when bicycling were 0.28% of total admissions (1 in 357 admissions). Mills[9] reported that 66% of cyclists' admissions were detained for just one night and most of the casualties with cranium injuries were admitted for overnight observation. Across Canada in 2003/04, there were approximately 2.5 million hospital admissions[10] including 16,811 for total head injuries. Motor vehicle-related head injuries accounted for 5970 admissions and cyclists 815 in total, 494 for 0-19 years of age and 321 for 20 years and above.[11] Cyclists admitted for head injuries represented approximately one in 3067 admissions. Cyclists average about 60 fatalities per year compared with vehicle occupants at 2120, pedestrians 365 and motorcyclists 200.[12]

Health benefit comparison
Moderate cycling has many physical and mental health benefits (BMA 1992[13]) by reducing the risk of developing heart disease,[14] diabetes, high blood pressure, colon cancer and depression, and helping to control weight and increase fitness. Dr Mayer Hillman from the UK's Policy Studies Institute calculated the life years gained by cycling outweigh life years lost in accidents by a factor of 20 to 1.[15] One report from Australia[16] stated that "Despite the perceived risks of cycling, the absolute magnitude of the risks is low, and the benefit-to-risk ratio is overwhelmingly positive; for chronic disease prevention, obesity reduction and mental health, the benefits are substantial".

In 2001, deaths in Canada[17] due to all circulatory disease were approximately 60,000 compared to 63 from cycling. Type 2 diabetes is one of the fastest growing diseases in Canada with more than 60,000 new cases yearly.[18] Per million population, approximately two cyclist deaths occur annually compared with 2000 from circulatory diseases. Exercise helps to avoid depression and annually about 3665 individuals commit suicide, including a youth category of approximately 500.[19] Exercise also helps to avoid stroke leading to brain damage. During 2003/04, 26,676 patients were admitted for ischemic stroke.[20] Physical inactivity, high blood pressure, obesity and diabetes continue to contribute to heart disease and stroke in Canada and cycling helps to avoid all these problems.

Energy comparison
Comparing the energy (kilojoules) used per person per kilometre of travel shows the bicycle uses the least energy. Average values are: bicycle 150, walker 230, motorcyclist 2100, car driver only 5000.[21]

Impact of helmet legislation on cycle use
Survey data from four provinces in Canada provides an indication of the effects of legislation and are considered in turn. Ontario, Nova Scotia, British Columbia and Alberta show legislation may have discouraged cycling. No survey data is available for New Brunswick. The lack of more extensive survey information means only a broad assessment can be made.

Ontario: legislation for under 18 years of age introduced October 1995
Table 2 shows details of approximate number of cyclists counted aged 5 –14 in East York, Toronto and the hourly rate has been calculated.[22] The surveys were mainly based on 111 hours of observation and large variations in the number counted can occur from year to year. The average hourly rate of a two, four and six year period is compared to see if cycling has been reduced.

Table 2

Survey year	1990	1991	1992	1993	1994	1995	1996	1997	1999	2001
Cyclists counted	910	1880	1560	980	1080	1230	1200	920	1130	450
Helmeted	30	300	380	440	460	570	820	610	500	210
% helmeted	4	16	25	44	43	46	68	66	45	46
Hourly rate	8.2	16.9	14.1	8.8	9.8	11.1	10.8	8.2	10.1	4.0
Two year comparison 94/95 to 96/97	9.8 + 11.1 = 20.9 20.9/2 = 10.45						10.8 + 8.2 = 19.0 19.0/2=9.5 9.5/10.45 = 0.91 (91%) **9% reduction**			
Four year comparison 92/95 to 96/99	14.1 + 8.8 + 9.8 + 11.1 = 43.8 43.8/4 = 10.95						10.8 + 8.2 + (8.2 + 10.1)/2 + 10.1 = 39.2/4 = 9.8 9.8/10.95 = 0.89 (89%) **11% reduction**			
Six year comparison 90/95 to 96/01	8.2 + 16.9 + 14.1 + 8.8 + 9.8 +11.1 = 69 69/6 = 11.5						10.8 + 8.2 + (8.2 + 10.1)/2 + 10.1 + (10.1 + 4)/2 + 4 = 50 50/6 = 8.33 8.33/11.5 = 0.72 (72%)* **28% reduction**			

Data on the hourly rate provides a guide and indicates cycling has been discouraged by 9%, 11% and 28% for two, four and six year comparisons respectively. The 1999 survey was reported to relate to a particularly sunny period[23] and 112 hours of observation. In contrast to Australia where enforcement by the police was widespread, it appears little if any enforcement was used in Toronto, with the helmet wearing rate returning to pre-law levels by 2001. Macpherson claimed no reduction in cycling had occurred due to the legislation[24] based on data (4.32 cyclists/hr for 1995) used in the 2001 report for East York. However this is not consistent with the survey details provided in 2003, that indicate 11.1 cyclists per

hour, as shown in Table 2. This therefore suggests the claim of no reduction is unreliable. No reply was provided to a detailed letter enquiring about the surveys, 'Worldwide helmet concerns', published e-Letters in Injury Prevention, 25 January 2008.

Nova Scotia: all age legislation introduced July 1997

In Nova Scotia, 49 days of surveys[25] over a three year period showed reduced counts of cyclists - 87.9 per day before the law in 1995/96, 33.5 in 1997 and 51.7 per day after helmet law enforcement in 1998/99. This indicates a drop of 62% [1-(33.5/87.9)] in 1997 and 41% [1-(51.7/87.9)] in 1998/99. The proportion of child cyclists observed decreased from 8.1% to 6.1% to 3.7% over the three years, indicating a drop of about 70% [(51.7 x 0.037)/(87.9 x 0.081) = 0.268].

British Columbia: all age legislation introduced September 1996

Surveys to mainly assess the helmet wearing rate were conducted in 1995 and 1999[26] with total counts of 3950 and 4246 respectively, indicating a 7.5% increase in cyclists (see Table 3). However, a number of elements regarding the surveys need to be mentioned. The survey information does not discuss weather conditions in detail but it seems 1995 had the wetter period with nearby Seattle precipitation for July and August 1995 at 3.15 inches, compared to 1999 at 2.1 inches.[27] Generally, Vancouver is wetter than Seattle and therefore it is very likely that the first survey had a lower than normal count. British Columbia also had an increase in population[28] over the period 1995-1999 (3.282 million in 1991 and 3.907 million in 2001 - +625,000) and invested in cycling facilities. Since 1990, Vancouver has built 16 bikeways that connect to form a network.[29]

Table 3

	1995 - %	estimated No	1999 - %	estimated No	% change
0-5 years	2	79	1.5	64	-19
6-15 years	18.5	731	20.5	870	+19
16-30 years	50	1975	35	1486	-24.8
Total 0-30	70.5	2785	57	2420	-13%
30+		1165		1826	+56
Total all ages		3950		4246	+7.5
Approximate hourly rate		29.92		32.16	

Population gain (200,000+) could largely account for the 7.5% increase in the count. The 1995 period seems to have been about 50% wetter than the 1999 survey period. Between 1980 and 1999, 1995 appears to be ranked about the second wettest and 1999 the fourth wettest. In late July 1995, Vancouver had some wet and windy weather that would have discouraged cycling.[30] Taking into account all these variables, it is very likely that the helmet law discouraged cycling - by 28% according to one estimation[31] based on injury statistics.

Alberta: legislation for under 18 years of age enforced May 2002

Table 4 details the number of cyclists counted before and after the Alberta helmet law was enforced[32]. The percentage reduction is shown below.

Table 4

Year	2000	2004	Reduction %
Age 0-17	164	41	75
Age 18+	474	230	51.5
Total	638	271	57.5

Cycle use - combined survey indications

The surveys generally only provide an indication of the level of cycling activity. Therefore, only a broad estimate can be made. Listing the data available and considering other indications such as accident statistics suggests reduced cycling of:

Ontario, East York (age 5-14 years) - 9%, 11% and 28%, average 10% (1994-98), average 16% (1990-2001).
Nova Scotia - 41%
British Columbia - 28%
Alberta - 57%

It is important to have an accurate value if possible when assessing the accident data. Ontario and British Columbia combined have about 75% of the total population of the provinces listed and weighting the results gives a value of about 26% for the overall reduction. Without Alberta, a similar calculation provides a figure of 20.5% (1990 – 2001). Specifically for the period 1994-1998, the reduction average would be approximately16%.

Assessing helmet effects on injury for children and youth aged 5-19 years

Tables 5 and 6 below show the estimated admissions for 'head' and 'other' injury rates for the provinces with and without legislation, for the 1994/98 period (refer Macpherson[33] Table 1 for 'head' and Table 2 for 'other' admission injury rates per 100,000 population comparisons). Survey data indicates cycling may have been discouraged by about 16% or more for the age group 5-19 years. Across Canada, head injury admissions have reduced for those in the 0-19 year age group by 53% between 1994/95 and 2003/04.[11] For cyclists aged 0-19 years, it reduced by 55%. Cyclists' length of stay in hospital for head injuries increased by 60% from 4.3 days in 1994/95 to 6.9 days in 2003-04.[11] Between 1994/95 and 1995/96, the average length of stay for cycling head injuries increased from 4.3 days to about 5.8 days, a gain of approximately 34%. For children, the helmet wearing rate in Ontario increased from about 43% to 68% for the period 1994/95 to 1995/96. Why the length of stay has increased by about 34% over a 12 month period is not obvious. Often in the past, cyclists with head injuries have been admitted for overnight observation and this practice may have been reduced because of the introduction of CT scanners providing more reliable information on head injury. A long-term trend of reduced admissions for cyclists with head injury may in part be due to CT scans.

Estimated Hospital admissions for cyclists aged 5 –19 years 1994 - 1998
Legislation provinces – Ontario, British Columbia, Nova Scotia and New Brunswick

Table 5 - Legislation provinces, population 3,262,595

Assessment based on a 16% reduction in cycling for legislative provinces

Table 5

With legislation	1994-95	1995-96	1996 -97	1997-98	94/98 % change	Reduced admissions 94/98
No. of head injury admissions	596	464	371	325		
% Head	100	77.8	62.2	54.5	45.5%	
Reduced No.- head		132	225	271		628
Assuming a 16% reduction	501					
Adjusted reduced No.- head		37	130	176	35%	343
No. of other injuries.	883	869	742	797		
% Other	100	98.4	84.0	90.2	9.8%	
Reduced No.- other		14	141	86		241
Assuming a 16% reduction	742					
Adjusted reduced No.- other		-127	0	-55	-7.4%	-182
Combined 'head' and 'other'						
No. head and other injuries	1479	1333	1113	1122		
Assuming a 16% reduction	1242					
Adjusted change No. head & other		-91	129	120	9.7%	**160***

Overall result: a reduction in admissions of approximately 160 from a calculated base level of 1242, down 13% over the period 1994-98 - a reduction of approximately 4% per year.

* Note: due to adjustments for the 16 % reduction, the figures do not quite tally.

Estimated hospital admissions for cyclists aged 5 –19 years 1994 - 1998
Provinces without legislation

Table 6 - Provinces without legislation, population 2,669,985

Table 6

Without legislation	1994-95	1995-96	1996 -97	1997-98	94/98 % change	Reduced injuries 94/98
No. of head injury admissions	490	435	390	356		
% Head	100	88.8	79.6	72.6	27.4%	
Reduced No.- head		55	100	134		289
No. of other injuries	948	800	763	734		
% Other	100	84.4	80.5	77.5	22.5%	
Reduced No.- other		148	185	214		547
No. head and other injuries	1438	1235	1153	1090		
Reduced No. head & other injuries		203	285	348	24.2%	836

Overall result: a reduction in admissions of 836 from a base level of 1438, down 42% over the period 1994-98 - a reduction of approximately 14% per year.

Comparing results

When adjusted for the estimated 16% reduction in cycling for legislative provinces, they had a reduction in admissions of 4% per year compared with 14% for non-legislative provinces i.e reductions in admissions of 160 compared with 836. The actual percentage reduction for total admissions was similar at 24.2% for both legislation and non-legislation provinces. Other factors to consider are non-legislative provinces had a greater number of cases involving motor vehicles and provinces with legislation tended to have a greater improvement in road safety. The results overall are surprising on first inspection, showing helmet requirements has effectively reduced safety. But Australian results are similar, showing reduced cycling and a higher accident rate associated with helmet use for those still cycling. Erke and Elvik 2007[34] stated: "There is evidence of increased accident risk per cycling-km for cyclists wearing a helmet. In Australia and New Zealand, the increase is estimated to be around 14 per cent." In Western Australia, head injuries fell by 11% to 21% but cycle use fell by 30% or more.[35] The risk of head injury for those who continued to cycle increased. Data of hospitalised Western Australia cyclists[36] shows an average 641 for the three years prior to helmet law enforcement. Allowing for an estimated 30% fall in the number cycling, hospital admissions should have fallen to about 449 cases. The actual average was 633. The European Cycling Federation stated[37] that "… the evidence from

Australia and New Zealand suggests that the wearing of helmets might even make cycling more dangerous."

Robinson 1996,[8] Table 3 and 5, shows the equivalent number of injuries for pre-law numbers of cyclists to increase following legislation: New South Wales 926 to 1595, up 72% approximately, and for Victoria 809 to 944, up 16% approximately. Helmet wearing and legislation reduced child safety and discouraged cycling.

In Canada the emphasis was placed on a 45% reduction in the head injury rate for provinces with legislation compared to non-legislation provinces of 27%.[38] This claim was made without any adjustment for the level of cycling activity. The head injury admissions rate due to people falling also fell for 0-19 years olds, 1994-98,[11], from about 4660 to 3450, a reduction of approximately 1210, compared to cyclists 1086 to 681, a reduction of 405. This large reduction in head injury admissions for non-cyclists indicates some caution should be used in claiming helmets are responsible for lowering head injuries as other factors may also be involved.

British Columbia did not introduce legislation until September 1996 and the 16% drop in cycling would be unlikely to apply for the 1995/96 year. The rate per 100,000 for 'other injuries' fell in BC from 41.6 in 1995/96 to 28.2[38] in 1996/97, a drop of 32%. This indicates a drop in cycling activity and also suggests a comparison between 1994/95 and the later periods of 1996/97 and 1997/98 may be worth considering as well. Tables 7 and 8 below provide the comparisons.

Table 7 reproduces Table 5 but without data for 1995/96 and shows the results.

Table 7

With legislation	1994-95		1996 -97	1997-98	94/98 % change	Reduced admissions 94/98
No. of head injury admissions	596		371	325		
% Head	100		62.23	54.51	45.49%	
Reduced No.- head			225	271		496
Assuming a 16% reduction	501					
Adjusted reduced No.- head			130	176	35%	306
No. of other injuries.	883		742	797		
% Other	100		84.03	90.24	9.76%	
Reduced No.- other			141	86		227
Assuming a 16% reduction	742					
Adjusted reduced No.-other			0	-55	-7.4%	-55
Combined head and other						
No. head and other injuries	1479		1113	1122		
Assuming a 16% reduction	1242					
Adjusted change No. head & other			129	120	9.7%	**250**

Overall result: a reduction in admissions of 250 over 24 months from a calculated base level of 1242. Estimated reduction in admissions of 10% per 12 month period for legislative provinces.

Table 8 reproduces Table 6 but without data for 1995/96 and shows the results.

Table 8

Without legislation	1994-95	1995 -96	1996 -97	1997-98	94/98 % change	Reduced injuries 94/98
No. of head injury admissions	490		390	356		
% Head	100		79.56	72.64	27.36%	
Reduced No.- head			100	134		234
No. of other injury admissions	948		763	734		
% Other	100		80.46	77.47	22.53%	
No. of other injuries	948		763	734		
Reduced No.- other			185	214		399
No. head and other injuries	1438		1153	1090		
Reduced No. head & other injuries			285	348		633

Overall result: a reduction in admissions of 633 over 24 months from a base level of 1438. Estimated reduction in admissions of 22% per 12 month period for non-legislative provinces.

Fatality trends for Canada

Assessing if helmet use has had an effect on the fatality rate is an important consideration. Changes in overall road safety, speed limits, drink driving changes, provision for cyclists, age group proportion of cyclists, cycle training provided, population variations, weather variations and level of cycling activity all combine to affect overall accident statistics and safety. Helmet use is only one of many factors involved. Between 1990 and 2004, Canada had a 42% improvement in road safety based on per million population. Cyclists' data below is based on ages 0-19 years and legislation applied to under 18 years of age in Ontario and Alberta, so minor changes to the data could be warranted.

Comparing cyclists subjected to legislation in the provinces of Ontario, New Brunswick, British Columbia and Nova Scotia for the six year periods either side of law enforcement, cyclist fatalities reduced by approximately 147 to 93 - a 37% reduction. Based on surveys and an estimated 20.5% reduction in cycling for legislative provinces, the effective reduction becomes 117 to 93, or 20.4%.

Comparing non-legislative provinces (Alberta, Newfoundland, Prince Edward Island, Quebec, Manitoba, Suskatchewan and Yukon NWT) in six years periods (1990-1995 and 1996-2001), there was a reduction from 278 to 196, or 29.5%. If including cyclists 20 years and older from Ontario, the figures become 360 to 279, a reduction of 23%.

As a background consideration, pedestrians also had reduced fatalities from 1990 to 2001: in six year periods (1990-1995 to 1996-2001) fatalities fell from 2881 to 2398, a reduction of 17%. Both provinces with helmet legislation and without had good reductions in cyclist fatalities. Overall road traffic deaths reduced from 3963 in 1990 to 2776 in 2001,[12] a reduction of 30%. Most of the reduction in cyclist fatalities could be due to improved road safety in general, as well as changes to behavior by children and fewer teenagers cycling.

Data from the Netherlands, where helmet use is low, provides a comparison for the period 1989 to 1992. Cycle use did not decrease (12.8, 13.0, 12.8 and 12.9 billion km from 1989 to 1992) but fatalities reduced from 333 to 251, a drop of 25% in just three years and without discouraging cycling.

The fatality trends[39] do not justify making strong claims, either positive or negative, for helmet use. The mania for helmet promotion is not warranted. People choosing to wear helmets may take fewer risks compared to teenagers who generally have the lowest wearing rates and also have higher accident rates. Helmet wearers are likely to wear or use other safety aids - lights or highly visible clothing are two examples. Comparing helmet wearers to non-wearers in fatality cases may not provide for a good scientific assessment due to other factors. A few cases have occurred in which children die due to being strangled by their helmet getting caught and the strap acting to strangle the child.

Civil liberties

Cycling can be convenient, pleasurable, healthy, environmental friendly and a low risk activity. Helmet requirements can impact on all of these benefits, making it less convenient, less pleasurable, discouraging cycling, adding to pollution and increasing the accident rate. Helmet requirements prevent cyclists from wearing hats that offer more sun protection, potentially increasing problems for people with skin cancer. They also prevent cyclists from riding without a helmet when feeling too hot. The Canadian Charter of Rights and Freedoms guarantees the rights and freedoms set out in it subject only to such reasonable limits prescribed by law as can be demonstrably justified in a free and democratic society. One criteria to justify the helmet laws is that helmet benefits have to exceed the disadvantages.[40] People also have a right to manifest their beliefs. If they believe they should be allowed to cycle without a helmet, helmet legislation prevents this.

The UK's National Children's Bureau (NCB) provided a detailed review in 2005[41] stating "the case for helmets is far from sound", "the benefits of helmets need further investigation before even a policy supporting promotion can be unequivocally supported" and "the case has not yet been convincingly made for compulsory use or promotion of cycle helmets." Subjecting people to a legal requirement to wear a helmet when the actual evidence for their use is far from clear is not sufficiently respectful of basic civil liberties values.

Approximately 16 times more motor vehicle occupants (n=5970) and people falling (n=7637) suffer head injuries than cyclists (n=815, 2003/4 data).[11] Discrimination can occur in accident compensation cases where a cyclist was not wearing a helmet, compared to pedestrians or indeed motor vehicle occupants who received head injuries. The helmet laws result in unfair compensation and a biased legal process affecting the civil liberties of people cycling without a helmet.

A primary issue is avoiding falls or head impacts. Being larger than the skull, helmets increase the number of impacts that could otherwise be near misses for a bare head. Dr Hillman[42] reported that "they do not protect the head from rotational trauma which can seriously damage the brain and brain stem and which is quite common when cyclists are hit

a glancing blow from a motor vehicle rather than in direct collision with it". Lane reported "it has been recognised since the work of Holbourn (1943) that rotational acceleration of the head plays a major part in brain injury".[43] Lane details the threshold limits suggested by Lowenhielm of 4500 rad/sec^2 for AIS 5 (AIS 5 being critical injury level, survival uncertain). The estimated tolerance acceleration limits for children are lower than for adults and the 4500 rad/sec^2 limit may be a safer criteria than the higher limits suggested for adults. Corner et al found by experiment that the addition of a helmet to the head can increase angular acceleration.[44]

Further research by StClair and Chinn from the UK showed that out of 43 tests for rotational acceleration, 23 exceeded the 4,500 rad/sec^2 level, three results were above 10,000 rad/sec^2, and a maximum value of 20,642 rad/sec^2 was obtained.[45] The test results were based on a nominal impact speed of 8.5m/s and in practice impact speeds can be much higher. Also, a limited range of helmet sizes, up to 57cm, were tested.

This research confirms dangerous levels of angular acceleration can result from wearing a helmet and in some cases will be higher than that for a bare head. Helmets, being larger than a bare head, also means a helmeted head will be more likely to sustain an impact. Data on the impact location on helmets also confirms most impacts actually occur on the side areas rather than the top, front or rear. Consequently, rotational considerations become even more important. StClair and Chinn research data shows that in the majority of impacts, values obtained exceeded the safer limit. However, they also claim that "in the majority of cases, the levels of rotational acceleration of a helmeted head would be no more injurious than expected for a bare, non-helmeted head". Due to the increased size of a helmeted head, in practice, a bare head could avoid an impact whereas a helmeted head could incur an impact. Therefore, the above claim is unsound.

The resulting combination of increased probability of impact to a helmeted head and higher angular acceleration compares unfavourably with a bare head. Hence, there can be no confidence that wearing a bicycle helmet of current design can ensure protection against serious injury to the brain. The standard for helmets represents the government's guarantee of their efficacy and absence of harmful effects. The advice and legal requirement to wear a helmet must therefore be judged to be unsafe because the current standard does not relate at all to angular acceleration. Particular caution is needed where the scientific knowledge is incomplete or shows harmful effects may result. Without testing helmets for rotational acceleration affects, helmet laws infringe civil liberties by mandating the use of a product that could increase the risk of serious injury.

The UK report RSRR30[46] reported 21 papers in favour of helmets or legislation compared with 22 against. The evidence supporting helmet use and legislation is clearly divided. Around the world, a few cycle helmet laws have been introduced for all ages, whilst others have been introduced for younger cyclists only, thus giving adults freedom of choice. In other areas, helmet laws have been rejected or at least not supported. Without legislation, helmet manufacturers and retailers promote helmets. The European Council of Ministers (ECMT) report on "National policies to promote cycling" (2004)[47] advises "leaving promotion to the manufacturers and shopkeepers". Dr Hillman[42] detailed his reasons for not promoting helmets after considering the evidence. He considered it could lead to fewer people cycling.

Helmet laws do not take account of people's individual beliefs and values or the circumstances and problems they may have in wearing or fitting a helmet. Therefore, even if the laws could be justified, they would still infringe some people's civil liberties by not allowing for their circumstances.

Summary assessment
Robinson 2006 reported 'No clear evidence from countries that have enforced the wearing of helmets',[48] showing helmets may not provide the benefits expected, including data from Canada. There may be no clear evidence of a benefit from imposing helmet legislation but there is considerable evidence showing negative effects as listed below.

Cycle use
There is evidence that helmet legislation has caused a reduction in cycling of about 20% or more in several provinces where surveys have been conducted. Evidence from other countries also shows cycling reduced due to helmet legislation. There is evidence of people not wishing to wear helmets and fines for people who have not been wearing one.

Health
With the health benefits of cycling resulting in life years gained outweighing life years lost in accidents by a factor of 20 to 1, if 5% of cyclists stopped cycling due to legislation then any benefit from helmets would be lost. Fatality data indicates more than 50% of cyclists may die due to non-head injuries. If cycling is discouraged by 2.5% or more, then it fails to benefit the overall health of the nation. With cycling being discouraged by approximately 20%, this indicates that in health terms the helmet laws caused far greater harm than good - by a factor of 8 to 1. In British Columbia between 1994/95 and 2004/05, 17% of cyclists aged 12 to 19 years changed from being active to moderately active.[49] Helmet legislation creates a problem for bicycle hire services as sharing helmets is a public health issue. Provinces without legislation can readily promote cycle hire.[50]

Accidents
In overall accident terms, helmet use result in more accidents than would otherwise occur. The assessment for 0-19 year olds shows that for legislative provinces, admissions reduced by approximately 160 compared to a reduction of 836 for non-legislative provinces over a four year period. Across Canada, cyclists' length of stay in hospital for head injuries increased by 60% from 4.3 days in 1994/95 to 6.9 days in 2003/04,[11] so there are additional concerns of minor head injuries changing to more serious ones. Clarke 2007 [3] lists two possible advantages of helmets compared to 13 possible disadvantages. Of the 13 disadvantages, 11 could tend to increase the accident rate compared to one advantage tending to reduce the accident rate. In practice, it is likely that helmets cannot be improved to such a degree as to overcome their disadvantages. Accidents to cyclists also strongly relate to the expectation of motorists encountering cyclists and driving more carefully. There is also a reasonable assumption that people discouraged from cycling will more frequently drive a vehicle for transport, increasing the safety risk for all road users including pedestrians, cyclists and motorists. Any discouraging effect due to the helmet laws directly relates to lowering the safety of cyclists still riding.[51]

Fatalities
It is certain that helmets have led to children being strangled but there is no strong evidence showing helmets reduce fatalities. Fatality data indicates more than 50% of cyclists may die due to non-head injuries. Sage et al[52] detailed that out of 20 bicycle riders fatally injured in Auckland, New Zealand, between 1974 and 1984, 16 died (80%) of injury to multiple organ systems. Their report stated that "wearing of suitable safety helmets by cyclists is unlikely to lead to a great reduction in fatal injuries". The BMA concluded in 2008 that for fatal accidents, the force of impact in such instances is considered so significant that most protection would fail.[53]

Environment

If fewer people cycle and transfer to other modes of transport, overall pollution is likely to increase. Per kilometre of travel, a car can use about 30 times more energy than cycling. In Australia, transport emissions rose 30% between 1990 and 2005 and this is expected to soar 67% above 1990 levels by 2020.[54] In addition to discouraging cycling and causing environmental harm, helmets use petroleum products in their manufacture - contributing to environmental damage.

Accident Compensation
Helmet laws result in unfair compensation and a biased legal process by using the excuse that the cyclist was not wearing a helmet. In cases of head injury, the perception that helmets offer a benefit is widespread, encouraging the view that it is justified to reduce payments if a cyclist does not wear one. Examining available evidence shows the perception is questionable as helmets have reduced safety in practice.

Law enforcement
It is unreasonable to prosecute children or their parents for cycling, which is beneficial to health, whilst encouraging through the same helmet law sedentary lifestyles which lead to worse health and greater costs for society. Police can use the helmet law to select or pick on people in some circumstances. Introducing a law that may often not be enforced but can be selectively enforced if police so choose fosters discrimination and discourages community respect for law. is not a good approach to fair legislation.

Conclusions
Helmet legislation in some provinces has not proved to be in the best interest of the health and safety of their populations. The health assessment shows that helmet legislation has done more harm than good by a factor of 8 to 1, largely due to discouraging cycling. There are indications that more people have become inactive in recent years and helmet legislation could be a contributing factor.

The accident assessment shows helmet legislation has resulted in reduced safety for legislative provinces compared to non-legislative provinces. Serious brain injury is often associated with high rotational acceleration[55] and helmets are not tested for rotational acceleration in meeting standard requirements. Helmet wearers, especially those requiring larger sizes, cannot be assured that their helmet will protect them from high rotational accelerations and they may increase such danger.[56]

The Netherlands seems to have the right approach: learn to ride safely with parents/grandparents showing and teaching safe and sensible riding, and provide good cycling facilities or wide on-road cycle lanes that avoid high speed and heavy vehicle traffic if possible. Helmet promotion draws attention away from worthwhile safety strategies and tends to focus on a single issue.

Some unresolved issues remain concerning helmet safety and it is certain that legislation has discouraged cycling, particularly when enforced. Helmet laws infringe civil liberties and the Canadian Charter of Rights and Freedoms by not being demonstrably justified. The health loss is estimated at eight times higher than possible gains. Helmet law effects in Canada appear to have resulted in the public being fined, subject to police involvement, loss of cycling health benefits and a reduction in civil liberties, as well as additional accidents and longer hospital stays for head injury.

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