Bicycle Safety Helmet Legislation and BIcycle-Related Non-Fatal Injuries in California (Working Paper – Please Do Not Quote)

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INTRODUCTION

Legislation that mandate people to wear bicycle safety helmets while using a bicycle has been used as a method of head injury prevention by a number of jurisdictions in Australia, Canada, New Zealand, and the United States for over a decade. Many helmet laws have been evaluated and most of these studies used helmet-wearing rates among bicyclists as a measure of the legislative effects. Few studies have associated bicycle-related injuries with legislation and of the ones found in the literature review that did, only six used state or nation wide hospital admissions or discharge data that represented the vast majority of injured bicyclists in a population (Cameron et al. 1994; Hendrie et al. 1999; Macpherson et al. 2002; Marshall and White 1994; Povey et al. 1999; Scuffham et al. 2000; Vulcan et al. 1992). Furthermore, of these six studies, only three analysed more than two years of post-legislation data (Hendrie et al. 1999; Povey et al. 1999; Scuffham et al. 2000), two of which used the same data source (Povey et al. 1999; Scuffham et al. 2000), and none examined helmet laws in the United States.

California was one of the first states to mandate the use of bicycle safety helmets in the United States. On 1 January 1994, a piece of legislation that required bicyclists ages 17 years and under to wear helmets while riding on public bicycle paths and roads became effective. Violation of this law was punishable by a fine of up to $25. The age limitation created a setting for a case-control comparison between young riders and adults.

This study used ten years of patient discharge records from all hospitals in California, from 1991 through 2000, to examine the relationship between the 1994 bicycle safety helmet legislation and bicycle-related injuries. There were 44,069 cases in total and each of them represented an injury event for a bicyclist and included seven variables: year, age, injury type, cause, county of residence, race/ethnicity, and sex. Two age groups, two time periods, and three injury types were defined for analysis. The study cases were young bicyclists who were required to use helmets and the controls were adults who were not; from here on after, these two groups will be referred to as *Youth* and *Adult*, respectively. The two periods were 1991 through 1993, pre-legislation, and 1994 through 2000, post-legislation. The three injury types included two for the head, Traumatic Brain Injuries (*Head-TBI*) and other injuries to the head, face, and neck (*Head-Other*), as well as one for all other injuries (*Other*).

The primary objective of this study was to examine whether the bicycle safety helmet legislation in California was associated with any statistically significant reductions in either or both types of head injuries among *Youth* riders. A case-control design was used to make direct comparisons between the two age groups across the two time periods. Since a direct measurement of risk exposure was not available, the proportion of each of the three injury types to the total number of injuries was used as the study outcome measure. It was assumed that the use of proportions would control for major changes in exposure from annual variations of bicycle use in the general population. The relative proportions were expected to remain reasonably constant unless an intervention, such as a bicycle safety helmet law, was introduced in the study period. Thus the study objective was to detect any significant reductions in the proportions of head injuries among *Youth* bicycle riders associated with the helmet law.

Two methods of analyses were applied to the injury data to meet the objective. The first was an aggregate data analysis approach using the Pearson chi-squared test for independence and odds ratios. This approach tested whether the relative proportions for the two age groups were significantly different across the two periods. The second method was a pooled disaggregate data fitting technique using Multinomial Logit (MNL) models. The MNL models examined the likelihood of each injury type outcome before and after the legislation and allowed for interactions between the age and year variables with the other ones to measure the explanatory power of each variable for the outcomes. Conclusions about the California bicycle helmet legislation were drawn from the results of these two methods.

EFFICACY OF BICYCLE SAFETY HELMETS

Although head injuries resulting from bicycling activities can be deadly, at least some of them are preventable. A number of case-control studies have shown, in varying degrees, that bicycle safety helmets are effective in protecting the head and the brain from injuries. In Seattle, Washington, R. Thompson et al. (1989) found that bicycle riders with helmets had 85% and 88% reductions in their risks of head and brain injuries, respectively. In a study of injured bicyclists in two Victorian hospitals, McDermott et al. (1993) found that bicycle helmets reduced the number of head injuries by 45%. This reduction is less than that found by R. Thompson et al. but the findings of these two studies are not directly comparable because of differences in injury classification and crash circumstances of the samples. Among studies on young bicyclists, British Columbia researchers reported that head and face injuries were 1.5 times more common to youths who did not use safety helmets than those who did (Linn et al. 1998) while an Australian group showed that helmet use reduced the risk of head injury and loss of consciousness to children by 63% and 86%, respectively (Thomas et al. 1994).

Members of the Seattle research group conducted another case-control study using a larger sample to assess the effectiveness of bicycle safety helmets against head injuries in different age groups and against facial injuries. The results indicated that helmets had a protective effect of 69% to 73% for 3 different categories of head injuries, and that there were substantial and similar levels of helmet protection against head injuries for all age groups (D. Thompson et al. 1996a). Furthermore, helmets were found to be equally effective for protecting the head in crashes involving motor vehicles and those not involving them. Bicycle safety helmets were also credited with providing significant protection for the upper and mid face but they did not appear to offer any protection to the lower face (D. Thompson et al. 1996b).

Overall, bicycle safety helmets have been found to be effective in protecting bicyclists against head, brain, and facial injuries. Two studies using meta-analysis techniques have summarized some of the research cited above plus others. Attewell et al. (2001) reviewed 16 studies with individual injury and helmet use data conducted from 1987 to 1998 and found that helmets reduced injuries to the head by 60%, brain by 58%, and face by 47%. In a review of 5 case-control studies, D. Thompson et al. (2002) had similar conclusions; helmets provided 69% reductions in risk of head and brain injuries.

BICYCLE SAFETY HELMET LEGISLATION

Several reviews on the prevention of unintentional injuries, like those experienced by bicyclists, recognised that legislation is an effective modifier of the safety behaviours of large segments of the population (Dowswell et al. 1996; Graitcer et al. 1995; Rivara et al. 1998; Schieber et al. 2000). Laws and regulations have been applied at various governmental levels throughout the world for an assortment of injury issues, including state and local ordinances requiring the use of bicycle safety helmets. The legislative assumption is that voluntary approaches, such as education and subsidy, cannot provide adequate protection to the public. Furthermore, mandatory laws for bicycle helmet use are considered relatively easy to implement as well as cost-effective (Hatziandreu et al. 1995) and helmet wearing is not an unusual hardship on individuals (Graitcer et al. 1995).

Provisions for government-sponsored education and subsidy programs, as well as penalties and enforcement of the law, are optional parts of any bicycle safety helmet legislation. Researchers have found, however, that bicycle helmet laws without any of these provisions are not as effective in increasing helmet use as ones combined with various supporting elements (Abularrage et al. 1997; Borgialli 1997; Coté et al. 1992; Dannenberg et al. 1993; Dowswell et al. 1996; Macknin and Medendorp 1994; Rodgers 2002; Schieber et al. 2000). Examples of penalties for violations of helmet laws vary from counselling and verbal warnings to fines. Policy makers generally accept that enforcement should focus on education and not punishment; some jurisdictions have provisions that permit a penalty to be waived if a violator provides proof of purchase of a bicycle safety helmet (Borgialli 1997).

An abundance of research from the United States, Australia, New Zealand, and Canada illustrate the various effects of bicycle safety helmet legislation. Overall, legislation has been credited with increasing helmet use among bicyclists (Coté et al. 1992; Dannenberg et al. 1993; Ni et al. 1997; Rodgers 2002; Schieber et al. 1996). The degrees of success to which the achievement of this goal could be attributed to helmet laws, however, varied from one locale to another and sometimes varied between different groups within one area. The literature suggested that the effects of bicycle safety helmet laws on helmet use were dependent on many other supporting factors. Bicycle safety education and public information campaigns regarding the benefits of helmets and the hazards of head injuries when they were not worn while riding a bicycle introduced a strong foundation for legislation (Finch et al. 1993). Positive attitudes toward bicycle safety helmets and public acceptance of a helmet law were critical for compliance (Finch 1996; Heathcote et al. 1999). In addition, provisions for an active enforcement and penalty system (Gilchrist et al. 2000; King and Fraine 1994), on-going education (Coté et al. 1992; Dannenberg et al. 1993), as well as subsidies for the purchase of helmets (Gilchrist et al. 2000; Macknin and Medendorp 1994), provided effective reinforcements that made such regulatory policies meaningful and their effects lasting.

A number of studies have tried to substantiate the relationship between the enactment of a bicycle safety helmet law and reductions in head trauma and most have found protective effects for legislation (Cameron et al. 1994; Grant and Rutner 2002; Hendrie et al. 1999;

LeBlanc et al. 2002; Macpherson et al. 2002). Some of them, however, used incomplete data sources such as police reports or insurance claims, which tend to bias towards motor vehicle-related crashes and leave out many non-motor vehicle ones. Also, the monitoring of bicycling activities is scarce and the few studies from Australia (Finch et al. 1993; Smith and Milthorpe 1994) and Canada (Macpherson et al. 2001) found contradicting results. The Australian studies found bicycle helmet safety legislations to be associated with reductions in bicycling activities while the Canadian study found no associations. Furthermore, most studies used data from within 3 years of the post-legislation period and few studies have examined the long-term effects of helmet laws. More research, therefore, is still needed concerning the effects of helmet legislation on bicycle-related head injuries and bicycling participation. Solid evidence on these two legislative outcomes is needed to accurately account for the benefits and costs.

CALIFORNIA BICYCLE-RELATED NON-FATAL INJURY DATA

The data used in this research project are disaggregate California hospital discharge records of bicycle-related non-fatal injuries for the years 1991 through 2000. The records were obtained from the Epidemiology and Prevention for Injury Control (EPIC) Branch of the California Department of Health Services and they were coded according to the clinical modification of the World Health Organization's *Manual of the International Classification of Diseases, Injuries, and Causes of Death, 9th Revision* (ICD-9-CM). External causes of injury codes (E-Codes) were used to describe the mechanism of injury (e.g., bicycle crash). Fatal injuries were not included in the analyses because the body part injured of the injury diagnosis is not available and, therefore, head and traumatic brain injuries, key indicators of associations with the bicycle safety helmet legislation, could not be identified.

The 44,069 bicycle-related cases from 1991 through 2000 were identified from the EPIC non-fatal injury database using ICD-9-CM E-Codes 810-819[.6], 800-807[.3], 820-825[.6], 826[.1, .9], and 827-829[.1]. Seven variables for each case were available for analysis: year, age, injury type, cause, county of residence, race/ethnicity, and sex. Cause was either motor vehicle related or non-motor vehicle related. The county of residence variable was transformed into density, which was categorized into Urban and Non-Urban. Urban included the densest counties and they represent the four largest population centres in California: Los Angeles, San Francisco, San Diego, and Sacramento. Race/ethnicity groups included *Asian*, *Black*, *Hispanic*, *White*, and *Other*.

EPIC defined the body part injured variable as the location on the body where the primary diagnosis was found. The primary diagnosis is the one that was primarily responsible for a patient being admitted to a hospital; it might have been the most serious problem a patient had but that is not always the case. For a patient with multiple injuries on different parts of the body, the body part injured variable only describe the part relating to the primary diagnosis for a particular injury event. As mentioned above, the three injury types of interest for analysis are *Head-TBI*, *Head-Other*, and *Other*.

Figures 1 and 2 respectively illustrate the percentages of the total number of cases for each type of injury in the *Youth* and *Adult* age groups. Representation in percentages controls for effects from variations of bicycle use in the general population (i.e., risk exposures) over the study period and highlights any protective effects of the helmet law.

Figure 1 clearly shows complimentary changes in the proportions of *Head-TBI* and *Other* injuries among *Youth* bicyclists over the 10 years. In 1991 and 1992, *Head-TBI* was at its highest level in proportions, at approximately 34%, while *Other* was at its lowest, at just under 60% in both years. Subsequently, *Head-TBI* injuries for youth steadily fell in proportions to about 24% in 2000 while *Other* rose to roughly 68%. Contrastingly, the proportions of *Head-Other* injuries remained constant at between 7% and 8% throughout the 10 years.

On the other hand, the proportions of the different types of injuries for the *Adult* group changed minimally from one year to another. As shown in Figure 2, over 70% of the total bicycle-related non-fatal *Adult* injuries were classified as *Other*. The rest were *Head-TBI*, at approximately 20%, and *Head-Other*, at just under 10%.

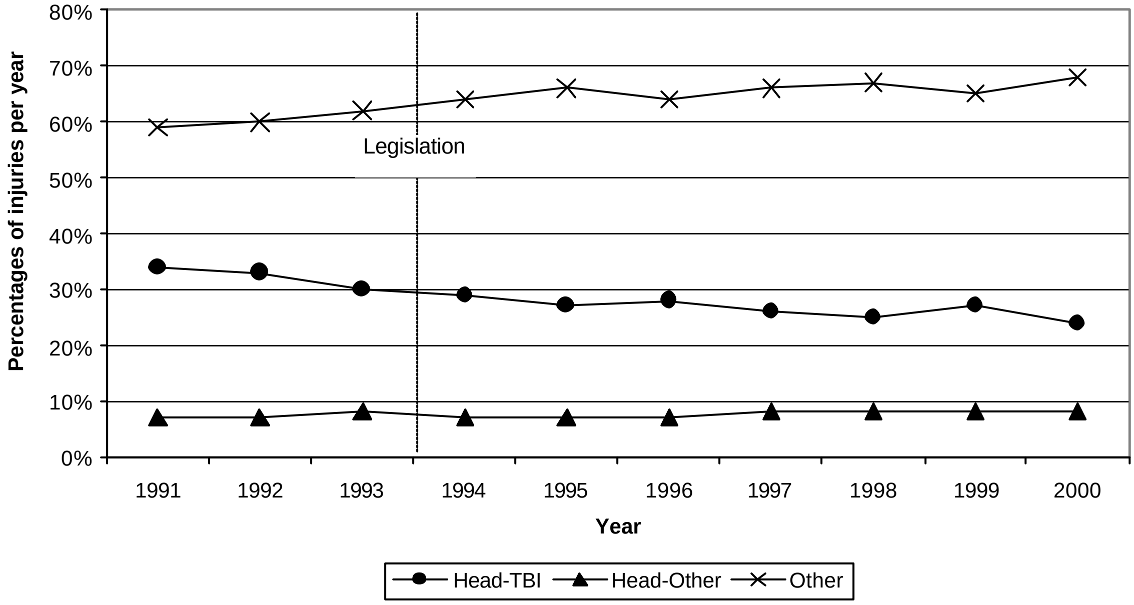

Figure 1 Bicycle-related non-fatal injuries in California – *Youth* cases, percentages of the total by injury type per year, 1991-2000

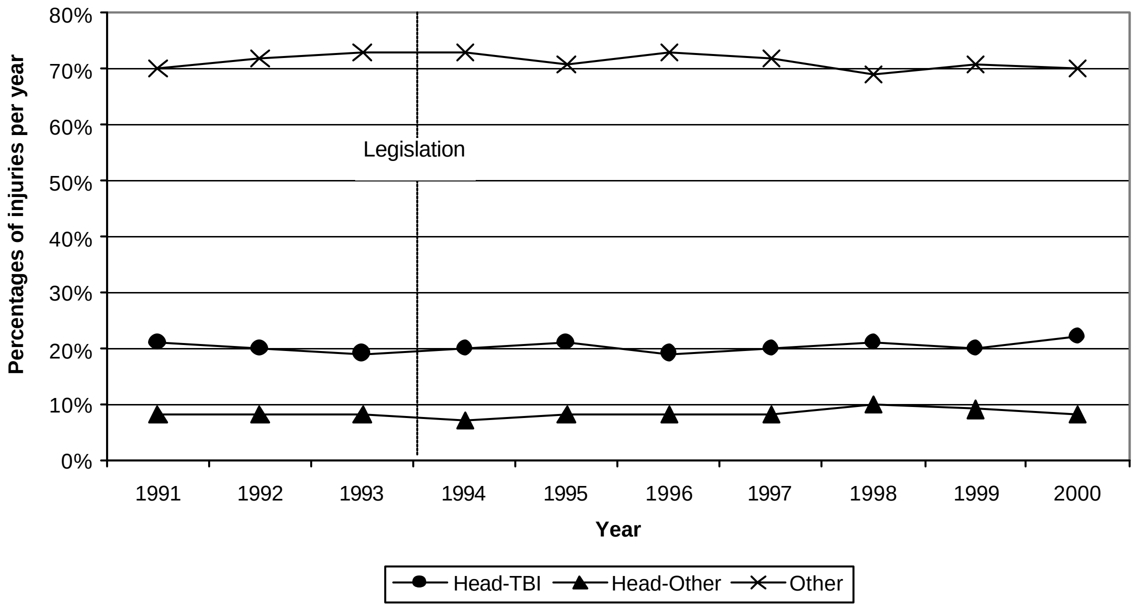

Figure 2 Bicycle-related non-fatal injuries in California – *Adult* cases, percentages of the total by injury type per year, 1991-2000

Together, Figures 1 and 2 indicate that controlling for changes in bicycle use, the likelihood of an injured *Youth* bicyclist having a *Head-TBI* injury as the primary diagnosis decreased during the study period but the corresponding likelihood for an injured *Adult* bicyclist remained constant. Figure 3 directly shows this in an Odds Ratios (OR) comparison of the likelihood of each injury type for a patient in the *Youth* group to one in the *Adult* group. OR is a common measure of association for two variables, which in this case were injury types and age. In the context of this study, an OR is defined as one proportion divided by another for a second variable, such as the proportion of *Head-TBI* injuries in one year for the *Youth* group divided by the corresponding proportion for the *Adult* group. As such, the OR is a measure of comparison going from the denominator to the numerator, which in this case is going from the *Adult* group to the *Youth* group. Figure 3 shows that for *Head-TBI* injuries in general, going from the *Adult* group to the *Youth* group resulted in a higher likelihood of having that injury as a primary diagnosis (i.e., OR > 1). The OR for *Head-TBI* injuries during the pre-legislation period was approximately 1.6. After the legislation, however, the OR for *Head-TBI* injuries decreased to just over 1 in 2000; the likelihood of such an injury for *Youth* patients was close to being the same as that for *Adult* patients. Meanwhile, the OR for *Other* injuries increased gradually from about 0.8 during the pre-legislation years to just less than 1 in 2000. *Head-Other* injuries, on the other hand, fluctuated between 0.8 and approximately 1 throughout the ten-year period.

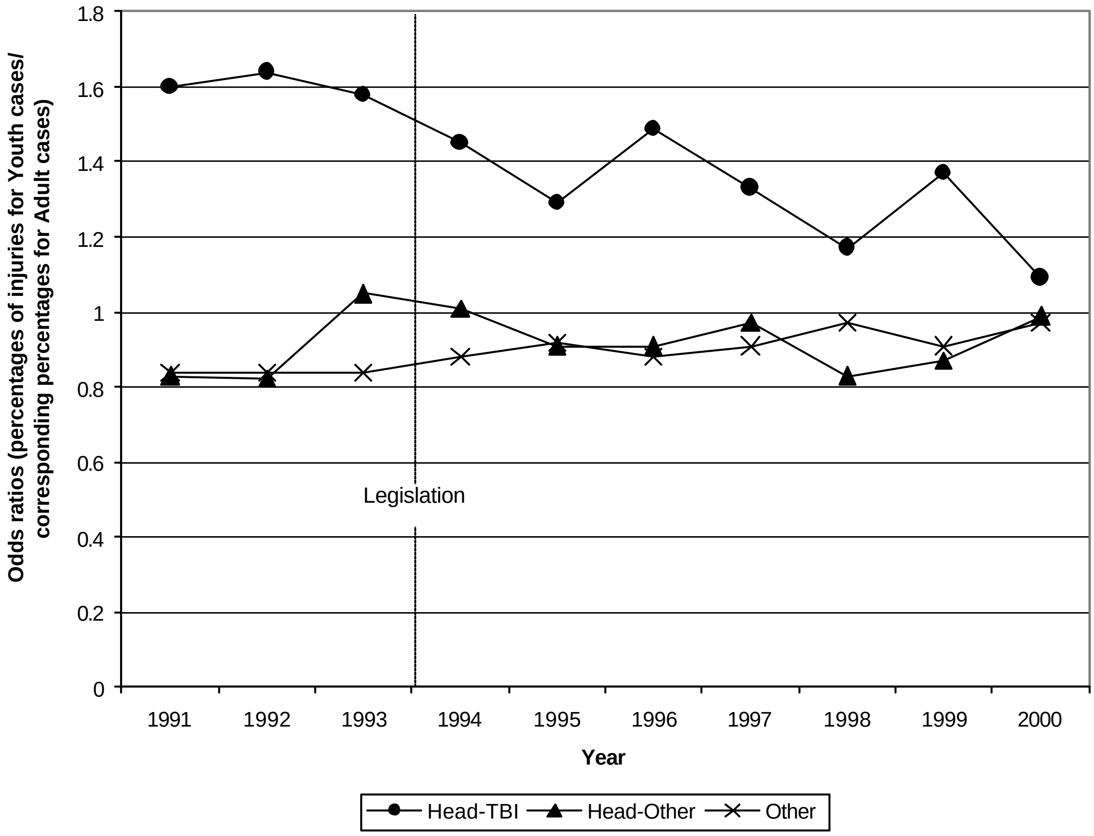

Figure 3 Bicycle-related non-fatal injuries in California – Odds ratios, percentages of the total by injury type for *Youth* cases compared to corresponding percentages for *Adult* cases, 1991-2000

AGGREGATE DATA ANALYSIS – PEARSON CHI-SQUARED TEST FOR INDEPENDENCE AND ODDS RATIOS

To test whether the changes among the proportions of injury types before and after the legislation for the *Youth* and *Adult* groups are statistically significant, the Pearson chi-squared test was applied to the aggregated data for each age group separately. The Pearson procedure can be used to test the hypothesis of independence of two variables of classifications (Walpole et al. 1998), which in this case were injury type and year. The null hypothesis for each age group was that the distribution of injury type proportions was independent of the period in which the injuries occurred. In other words, the hypothesis stated that the distribution of injury type proportions did not change significantly over time in the ten-year period.

The expected proportions of injury types for each period were calculated, assuming the above hypothesis was true, and the goodness of fit between the expected and observed proportions was computed according to the Pearson chi-squared test. For the *Youth* group, the hypotheses that the distribution of injury type proportions was independent of the period was significantly rejected, at greater than 99.9% confidence (one-tailed probability of chi-squared distribution, $P < 0.001$). This was expected from the plot patterns of the injury types shown in Figure 1. For the *Adult* group, the hypothesis that the distribution of injury type proportions among injured *Adult* bicyclists was independent of the period could not be rejected ($P = 0.505$).

The rejection of the hypothesis of independence for *Youth* meant that the distributions of injury type proportions for this group were not statistically the same between the two periods. Since there were three injury types, however, this result could not reveal whether all the proportions changed over time or that the proportion of one type of injury remained constant, as shown for *Head-Other* among *Youth* bicyclists in Figure 1. In order to accomplish this, the OR values were computed. An OR is as defined previously for Figure 3 but this time, the two variables being compared are injury types and time, instead of injury types and age. As such, the OR values for each age group are the proportions of each injury type in the post-legislation period divided by the corresponding proportions in the pre-legislation period. In other words, these are measures of comparisons for each injury type going from the pre-legislation period to the post-legislation period. Tables 1 and 2 summarised the results of the OR calculations, which included the 99.0% confidence intervals (CI).

Table 1 Bicycle-related non-fatal injuries in California – *Youth* cases, odds ratios, proportions of the total by injury types for the pre-legislation period compared to corresponding proportions for the post-legislation period

Type of injuries	Pre-legislation, 1991-1993 [A]	Post-legislation, 1994-2002 [B]	Odds ratios [B/A]
Head-TBI	0.327 (1) (0.313 – 0.341) (2)	0.268 (0.258 – 0.277)	0.818 (0.757 – 0.885)
Head-Other	0.0710 (0.0634 – 0.0785)	0.0765 (0.0708 – 0.0823)	1.08 (0.901 – 1.23)
Other	0.602 (0.588 – 0.612)	0.656 (0.646 – 0.666)	1.09 (1.05 – 1.13)

Notes: (1) Proportion of the total number of cases for that period
(2) 99.0% CI

Table 1 showed that the calculated OR values for the *Youth* group were 0.818 (99.0% CI: 0.757 – 0.885) for *Head-TBI*, 1.08 (0.901 – 1.23) for *Head-Other*, and 1.09 (1.05 – 1.13). These results showed that there was a significant reduction, 18.2% (11.5% – 24.3%), in the proportion of *Head-TBI* injuries among injured bicyclists in the *Youth* group going from the pre-legislation period to the post-legislation period. There was a corresponding increase of 9% (5% – 13%) in the proportion of *Other* injuries. At the same time, there was no significant change for *Head-Other* injuries since the 99.0% CI for this injury type included 1.

Table 2 Bicycle-related non-fatal injuries in California – *Adult* cases, odds ratios, proportions of the total by injury types for the pre-legislation period compared to corresponding proportions for the post-legislation period

Type of injuries	Pre-legislation, 1991-1993 [A]	Post-legislation, 1994-2002 [B]	Odds ratios [B/A]
Head-TBI	0.203 (1) (0.192 – 0.214) (2)	0.205 (0.198 – 0.212)	1.01 (0.926 – 1.10)
Head-Other	0.0793 (0.0721 – 0.0866)	0.0833 (0.0786 – 0.0880)	1.05 (0.908 – 1.22)
Other	0.718 (0.705 – 0.730)	0.712 (0.704 – 0.719)	0.992 (0.965 – 1.02)

Notes: (1) Proportion of the total number of cases for that period
(2) 99.0% CI

For the Adult group, Table 2 confirmed the results from the Pearson chi-square test result; there were no significant changes for any type of injuries between the pre- and post-legislation periods.

POOLED DISAGGREGATE DATA ANALYSIS – MULTINOMIAL LOGIT MODELS

In this section, a pooled disaggregate data analysis method was used to examine whether the different age groups within the *Youth* category experienced the same effects. Furthermore, the question of whether other variables were associated with this decrease is explored.

A Multinomial Logit (MNL) disaggregate data fitting technique was used to model the likelihood of an individual in the dataset having a particular type of injury as the primary diagnosis. A logit model is a mathematical tool that describes the dependence of a set of mutually exclusive and collectively exhaustive outcomes on explanatory variables that represent the attributes associated with each alternative as well as the characteristics of the individual. An MNL model can express the likelihood of an outcome within a set of two or more alternatives and in this application, the outcome alternatives were the three injury types: *Head-TBI*, *Head-Other*, and *Other*. The explanatory variables included in this study were age, year, cause, density, race/ethnicity, and sex and each variable is composed of two or more categories. Two models were developed, the first one explored two-way interactions between the age and year variables. The *Youth* category was subdivided into four smaller age groups and the aim was to investigate how the likelihood of the different injury types varied between different segments of bicyclists subjected to the helmet law across the pre- and post-legislation periods. The second model introduced three-way interactions of the two primary age categories, i.e., *Youth* and *Adult*, and year with other variables. These three-way interactions would reveal how cause, density, race/ethnicity, and sex contributed to each type of injury outcome in relations to the legislation. Results of these two models are shown in Tables 3 and 4.

The MNL modeling approach requires that one outcome alternative and one category for each variable be nominated as a baseline and the likelihood for all other alternatives and categories be calculated relative to this reference. An estimated parameter for an alternative and category specific variable used in an MNL model, therefore, measures the difference in likelihood between two alternatives and two categories. The higher the value of the parameter, the larger the difference is in absolute terms, and the more impact the variable has in expressing the difference in the likelihood for the two alternatives and two categories.

Table 3 Multinomial logit model I – Results, two-way interactions: age and year

Variable	**Reference Parameter**	**Model Parameter**		**Parameter Estimate**	**t-stat** (1)	**P** (2)
Constant	*Other* injuries	*Head-TBI* injuries		-0.991	-25.6	0.0000
		Head-Other injuries		-2.24	-37.4	0.0000
Age	*Adult*	0-4 years	*Head-TBI*	0.394	3.87	0.0001
			Head-Other	-0.103	-0.597	0.5508
		5-9 years	*Head-TBI*	0.693	14.7	0.0000
			Head-Other	0.171	1.949	0.0513
		10-13 years	*Head-TBI*	0.693	14.7	0.0000
			Head-Other	0.0526	0.599	0.5491
		14-17 years	*Head-TBI*	0.567	8.85	0.0000
			Head-Other	-0.128	-1.07	0.2843
Year	Pre-law (1991-1993)	Post-law (1994-2000)	*Head-TBI*	0.00534	0.165	0.8687
			Head-Other	0.0404	0.838	0.4022
Cause	Motor vehicle-related	Non-motor vehicle-related	*Head-TBI*	-0.413	-17.7	0.0000
			Head-Other	-0.210	-5.74	0.0000
Density	Non-urban	Urban	*Head-TBI*	0.0511	1.97	0.0489
			Head-Other	0.261	6.13	0.0000
Sex	Male	Female	*Head-TBI*	-0.064	-2.30	0.0215
			Head-Other	-0.181	-3.97	0.0001
Race/ ethnicity	White	Asian	*Head-TBI*	0.138	2.52	0.0119
			Head-Other	-0.00348	-0.05	0.9604
Age-Year-Interaction	*Adult* & Pre-law	Black	*Head-TBI*	-0.248	-5.27	0.0000
			Head-Other	0.149	2.23	0.0259
		Hispanic	*Head-TBI*	0.029	1.10	0.2695
			Head-Other	0.183	4.47	0.0000
		Other	*Head-TBI*	0.132	2.52	0.0118
			Head-Other	0.134	1.25	0.2098
		0-4 years & Post-law	*Head-TBI*	-0.470	-3.57	0.0004
			Head-Other	-0.237	-1.06	0.2893
		5-9 years & Post-law	*Head-TBI*	-0.382	-6.58	0.0000
			Head-Other	-0.227	-2.10	0.0359
		10-13 years & Post-law	*Head-TBI*	-0.211	-3.70	0.0002
			Head-Other	-0.0613	-0.569	0.5691
		14-17 years & Post-law	*Head-TBI*	-0.193	-2.47	0.0133
			Head-Other	0.256	1.85	0.0642

Notes: (1) Student t-statistics
(2) Two-tailed probability of Student t-distribution

Table 3 revealed that controlling for other variables and relative to the reference *Adult* group and the pre-legislation period, all subgroups within the *Youth* category had decreases in the likelihood of *Head-TBI* injuries, as indicated by the statistically significant negative estimates of the parameters. The youngest group, 0-4 years, had the most negative parameter and had, therefore, the greatest decrease. Each subsequent age subgroup that is older than 0-4 years had less negative parameter, indicating that the legislation was associated with smaller decreases in the likelihood of *Head-TBI* injuries with the older *Youth* bicyclists. For *Head-Other* injuries, the 5-9 years subgroup was the only one that had a significant decrease in likelihood. Furthermore, the 14-17 years subgroup had a positive and significant parameter estimate, which revealed an increase in the likelihood of that type of injury.

Table 4 Multinomial logit model II – Results, three-way interactions: age and year with other variables

Variable	Reference Parameters	Model Parameter		Parameter Estimate	t-stat [1]	P [2]
Constant	*Other* injuries	*Head-TBI* injuries		-1.02	-24.8	0.0000
		Head-Other injuries		-2.29	-34.8	0.0000
Age	*Adult*	*Youth*	*Head-TBI*	0.639	16.8	0.0000
			Head-Other	0.0387	0.651	0.5153
Year	Pre-law (1991-1993)	Post-law (1994-2000)	*Head-TBI*	0.00172	0.0531	0.9577
			Head-Other	0.0386	0.831	0.4062
Cause	Motor vehicle-related	Non-motor vehicle-related	*Head-TBI*	-0.396	-14.5	0.0000
			Head-Other	-0.171	-4.23	0.0000
Density	Non-urban	Urban	*Head-TBI*	0.0667	2.34	0.0190
			Head-Other	0.252	5.14	0.0000
Sex	Male	Female	*Head-TBI*	-0.128	-3.83	0.0001
			Head-Other	-0.177	-3.86	0.0001
Race/ ethnicity	White	Asian	*Head-TBI*	0.202	3.45	0.0006
			Head-Other	0.133	2.02	0.0436
		Black	*Head-TBI*	-0.312	-6.34	0.0000
			Head-Other	0.0681	0.974	0.3302
		Hispanic	*Head-TBI*	0.107	3.41	0.0006
			Head-Other	0.296	6.38	0.0000
		Other	*Head-TBI*	0.180	2.29	0.0221
			Head-Other	0.110	0.966	0.3339
Age-Year Interaction	*Adult* & Pre-law	*Youth* & Post-law	*Head-TBI*	-0.132	-2.21	0.0270
			Head-Other	0.175	1.58	0.1148
Age-Year-Cause Interaction	*Adult*, Pre-law, & Motor vehicle-related	*Youth*, Post-law, & Non-motor vehicle-related	*Head-TBI*	-0.0767	-1.50	0.1330
			Head-Other	-0.147	-2.12	0.0338
Age-Year-Density Interaction	*Adult*, Pre-law, & Non-urban	*Youth*, Post-law, & Urban	*Head-TBI*	-0.0501	-1.11	0.2672
			Head-Other	0.0456	0.514	0.6072
Age-Year-Sex Interaction	*Adult*, Pre-law, & Male	*Youth*, Post-law, & Female	*Head-TBI*	0.216	3.40	0.0007
			Head-Other	-0.0145	-0.21	0.8352
Age-Year-Race/ ethnicity Interaction	*Adult*, Pre-law, & White	*Youth*, Post-law, & Asian	*Head-TBI*	-0.259	-2.96	0.0031
			Head-Other	-0.618	-2.72	0.0065
		Youth, Post-law, & Black	*Head-TBI*	0.123	1.85	0.0644
			Head-Other	0.147	1.57	0.1155
		Youth, Post-law, & Hispanic	*Head-TBI*	-0.305	-5.51	0.0000
			Head-Other	-0.430	-4.99	0.0000
		Youth, Post-law, & Other	*Head-TBI*	-0.175	-1.46	0.1429
			Head-Other	-0.011	-0.0508	0.9595

Notes: (1) Student t-statistics
(2) Two-tailed probability of Student t-distribution

Table 4 revealed that the decrease in likelihood for *Head-TBI* injuries during the post-legislation period for the *Youth* group was not statistically different for motor vehicle-related incidents and non-motor vehicle-related ones. Similarly, the decrease was the same for residents non-urban and urban counties. The age-year-sex interaction, however, revealed that the decrease was greater for males than females. Also, the age-year-race/ethnicity interaction revealed that the Asian, Hispanic, and Other categories had greater decreases in the likelihood of *Head-TBI* injuries relative to the White group. Blacks, on the other hand, had a smaller decrease than Whites.

DISCUSSIONS

The Pearson chi-squared test that examined the independence of the injury type and time variables and the OR calculations showed that there was a statistically significant decrease in the proportion of *Youth* bicyclists with *Head-TBI* injuries as their primary diagnosis when comparing the post-legislation period with the pre-legislation period. The OR value of 0.818 (99.0% CI: 0.757 – 0.885) indicated that there was a 18.2% (11.5% – 24.3%) drop in the proportion of *Head-TBI* injuries among injured *Youth* bicyclists associated with the bicycle safety helmet legislation. There was a corresponding increase of 9% (5% – 13%) in the proportion of *Other* injuries and a possible, but statistically insignificant, increase for *Head-Other* injuries. On the other hand, there was no statistically significant change in the proportions among the three injury alternatives for the *Adult* patients. This is an important distinction because these results revealed for some reason or reasons, the proportions of injuries for one age segment (*Youth*) of injured bicyclists changed while another one (*Adult*) remained constant. Furthermore, the group with the static proportions was the one that was not subjected to the bicycle safety helmet law. Whereas the group with the changing proportions, also the one subjected to the helmet law, had a decrease in the percentage with *Head-TBI* injuries, which was a type of injury that is preventable with the use of bicycle safety helmets (R. Thompson et al. 1989; Thomas et al. 1994; D. Thompson et al. 1996a). It is, therefore, reasonable to state that one reason, if not the main reason, for the decrease in the proportion of injured *Youth* bicyclists with *Head-TBI* injuries across the pre- and post-legislation periods to be the enactment of the helmet law.

If the bicycle safety helmet legislation did have an effect on decreasing the percentage of *Head-TBI* injuries among its intended subjects, then one may question why a decrease was not also found in the percentage of *Head-Other* injuries for this group. Furthermore, even if the helmet law had no protective effects on *Head-Other* injuries, why did the percentage of this type of injury appeared to have increased, though insignificantly, from the results of the aggregate analyses instead of remaining constant. There are two parts to the response to these questions: which body parts *Head-Other* injuries include and what happens to the injury data if bicycle safety helmets do prevent *Head-TBI* injuries.

The *Head-Other* term refers to the “Other head, face, and neck” body region and this category encompasses many combinations of body parts and injury diagnoses against which a bicycle safety helmet would not protect. Specifically, *Head-Other* injuries include the dislocation of the face, fractures as well as sprains and strains of the face and neck, and open wounds to the face, neck, and eye. One study by D. Thompson et al. (1996b) did show an association between wearing a bicycle safety helmet and a reduced chance of injuries to upper and mid parts of the face but those effects were limited and there were no protectiveness found for the lower face or neck. It is, therefore, not unreasonable that the decrease in the percentages of *Head-TBI* injuries found in this study for those subjected to the helmet law was not accompanied by a decrease in *Head-Other* injuries.

To understand why the percentage of *Head-Other* injuries among *Youth* bicyclists might have possibly increased instead of remaining constant, one must consider what could have happened when the percentage of *Head-TBI* injuries decreased. Consider the following example. If there were 100 bicycle-related injuries the year before a helmet legislation was enacted and of these patients, 25 had *Head-TBI* as the primary diagnosis, 10 *Head-Other*, and the rest *Other*, then the respective percentages for each type of injury would be 25%, 10%, and 65%. Assume that in the following year, the helmet law took effect, five *Head-TBI* injuries were prevented and these five bicyclists escaped hospitalisation all together, and the number of other bicycle-related injuries remained the same, then the respective percentages for this post-legislation year would be 21.0%, 10.5%, and 68.4%. Cases dropping out of the dataset because *Head-TBI* injuries were prevented could cause the percentages of other outcomes to increase even though the number of *Head-Other* and *Other* injuries did not increase. Now consider the case if these five bicyclists were protected from *Head-TBI* injuries but were not lucky enough to escape hospitalisation, then they would each be get classified as either of the two other outcomes. The percentage of *Head-TBI* would still drop, to 20%, but the other two percentages could only remain the same or increase. If bicycle safety helmet legislation had absolutely no protective effects on *Head-Other* injuries, then the percentage of patients with *Head-Other* injuries could have, at best, remained the same if all the *Head-TBI* cases were “transferred” to *Other*. It would, however, not only be reasonable, but also probable, that the proportions of *Head-Other* injuries increased relative to the other two.

Realistically, it is conceivable that the helmet law could have had some protective effects on *Head-Other* injuries and, therefore, it would be possible for the percentage of this injury type to have remained the same, increased, or decreased. This, however, was not determined by the aggregate data analyses and is left for the pooled disaggregate data modeling. The disaggregate analysis also discerned the relationships between the likelihood of each injury type and the other variables.

In the disaggregate analyses, the first MNL model explored the two-way interaction between age and year and the results confirmed the findings of the aggregate analyses. *Youth* bicyclists had a decrease in the likelihood of *Head-TBI* injuries but this change that was associated with the legislation was not the same for everyone within this age group. The youngest riders, ages 0 through 9 years, had the greatest decrease while the oldest teenagers subjected to the helmet law had the smallest decrease. This distribution of effects is consistent with the research literature, which indicated that the senior high school student segment of the population usually had the lowest helmet use rates and was found to be the most unaffected by legislative interventions (Finch 1996; Heathcote et al. 1999). Furthermore, peer pressure was found to be an important factor for not wearing helmets (Cryer et al. 1998; Lajunen and Räsänen 2001) and it would not be unreasonable to assume that this age group was subjected to a significant amount of it. For *Head-Other* injuries, the likelihood of this outcome actually decreased for all *Youth* age groups in the post-legislation period except for those who were 14 through 17 years of age. It is unclear, however, why only this subgroup had an increase, particularly when it only had a small corresponding decrease in the likelihood of *Head-TBI* injuries.

The second MNL model examined three-way interactions that combined age and year with the cause, density, sex, and race/ethnicity variables. For the age-year-cause interactions, the legislation was associated with similar decreases in the likelihood of *Head-TBI* injuries for both motor vehicle-related and non-motor vehicle-related incidents among *Youth* bicyclists. The interactions also showed that the likelihood of the *Head-TBI* outcome was significantly higher for the motor vehicle category, which was expected since encounters with motor vehicles tend to be more intense. As for the age-year-density interactions, it is important to keep in mind that the density variable refers to the population density of the county of residence for the injured bicyclists. The county where a patient resided is not necessarily the same one where the injury occurred. It is, however, reasonable to assume that in most cases, particularly for *Youth* riders, the county of residence and the county where the injury occurred are the same. Research in the use of bicycles in the United States have shown that young riders spend most of their bicycle riding time on neighbourhood streets, sidewalks, and playground (Rodgers 2000). Furthermore, if there were local helmet promotion initiatives that might have affect the residents of some counties and not others, then it might show up in this interaction term. The results showed that the decrease in the likelihood of *Head-TBI* injuries and the increase in the likelihood of *Head-Other* injuries were not different for non-urban and urban counties.

The last two interaction terms had some confounding results that are more difficult to explain. For the age-year-sex interactions, there was a greater decrease in the likelihood of *Head-TBI* injuries for males than for females. There are undoubtedly differences between the riding behaviours of males and females. Research surveys showed that males accounted for just over 50% of the bicycle riders in the United States (Rodgers 2000) and assuming that this participation rate held true in California, it is very significant that the percentage of males in this non-fatal injury dataset is over 80%. Even accounting for the fact that the average male in the *Youth* bicycling group would spend more time riding than the average female, the national injury rate for males was still 50% higher than for females (Rodgers 2000). For some reason, male bicyclists tend to be more injury prone. This difference, however, does not adequately explain the decrease in the likelihood of *Head-TBI* injury for males and the increase for females. Perhaps it is possible that the differences between the sexes made it more acceptable for young males to wear a helmet than for young females but there is no evidence to support this.

Finally, for the age-year-race/ethnicity interactions, the legislation was associated with decreases in the likelihood of *Head-TBI* injuries for all categories of *Youth* riders except for Blacks. In addition, the likelihood for both types of head injuries decreased significantly relatively to *Other* injuries for young Asians and Hispanics. It appeared that the association with the legislation was particularly strong for these two groups. Possible reasons for the differences in effects for the different races or ethnicities are different cultural attitudes towards obeying the law and different socio-economic conditions. One may also consider that these results were products of a small number of records for these groups. For example, Asians and Blacks only accounted for 3.7% and 6.4%, respectively, of all records. Hispanics, however, accounted for 23.8%, and the utilities for this group were definitely statistically significant.

CONCLUSIONS

The bicycle safety helmet legislation in California was found to be associated with a 18.2% (11.5% – 24.3%) decrease in the proportion of traumatic brain injuries among injured youth bicyclists, 17 years of age and under, who were subjected to the law. The proportion of other head, face, and neck injuries were not significantly changed across the pre- and post-legislation periods in this age group but there was a corresponding increase of 9% (5% – 13%) in the proportion of all other injuries. On the other hand, there was no statistically significant change in the proportions of all three injury outcomes for *Adult* bicyclists, who were not subjected to a helmet law.

Of those bicyclists who were subjected to the bicycle safety helmet legislation, the youngest riders, ages 0 through 9, had the greatest decrease in the likelihood of having traumatic brain injuries as the primary injury diagnosis. Teenagers from 14 through 17 years, on the other hand, had the smallest decrease.

The decrease in the likelihood of traumatic brain injuries associated with the helmet law for youth bicyclists under the age of 18 years was similarly significant for motor vehicle and non-motor vehicle-related incidents as well as for residents of non-urban and urban environments. For unexplainable reasons, the bicycle safety helmet legislation was associated with a decrease in the likelihood of traumatic brain injuries for male youth bicyclists but not for female youth bicyclists and for all races except for Blacks.

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