Bicycle Safety Helmet Legislation and Bicycle-Related Non-Fatal Injuries in California

Brian Ho-Yin Lee, Joseph L. Schofer, and Frank S. Koppelman

B. H. Y. Lee (Corresponding Author)

Current affiliation:
Interdisciplinary Ph.D. Program in Urban Design and Planning
Department of Urban Design and Planning,
College of Architecture and Urban Planning
University of Washington
410 Gould Hall, Box 355740
3949 15th Avenue N.E.
Seattle, Washington, U.S.A. 98195-5740
Phone: 206.579.9877
Fax: 206.685.9597
Email: bhylee@u.washington.edu

Former affiliation (when researched was performed):
Department of Civil and Environmental Engineering
Robert R. McCormick School of Engineering and Applied Science
Northwestern University
Evanston, Illinois, U.S.A.

J. L. Schofer

Department of Civil and Environmental Engineering
Robert R. McCormick School of Engineering and Applied Science
Northwestern University
A332 Technological Institute
2145 Sheridan Road
Evanston, Illinois, U.S.A. 60208-3109
Phone: 847.491.8795
Fax: 847.491.7300
Email: j-schofer@northwestern.edu

F. S. Koppelman

Department of Civil and Environmental Engineering
Robert R. McCormick School of Engineering and Applied Science
Northwestern University
A318 Technological Institute
2145 Sheridan Road
Evanston, Illinois, U.S.A. 60208-3109
Phone: 847.491.8794
Fax: 847.491.7300
Email: f-koppelman@northwestern.edu

Final submission Date: 09 November 2003

Word Count: 7,525 (including abstract, tables, and figures)

Abstract: The objective of this study was to determine whether the bicycle safety helmet legislation in California, enacted in 1994, was associated with statistically significant reductions in head injuries among bicyclists 17 years and under who were subjected to the law. The study used 44,069 patient discharge cases from all public hospitals in California, from 1991 through 2000, and a case-control design to make direct comparisons between those subjected to the law (*Youth*) and those who were not (*Adult*), across the pre- and post-legislation periods. An aggregate data analysis approach and a pooled disaggregate data fitting technique using multinomial logit models were applied. The legislation was found to be associated with a reduction of 18.2% (99% confidence interval: 11.5%-24.3%) in the proportion of traumatic brain injuries (*Head-TBI*) among *Youth* bicyclists. 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 injury outcomes for *Adult* bicyclists. The youngest riders, ages 0-9 years, had the greatest decrease in the proportion of *Head-TBI*. The reduction was the same for motor vehicle and non-motor vehicle-related incidents. The bicycle safety helmet legislation was associated with a decrease in the likelihood of *Head-TBI* for non-urban residents but not for urbanites, for males but not for females, and for Whites, Asians, and Hispanics, but not Blacks and others.

INTRODUCTION

Legislation that mandates bicyclists to wear safety helmets 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 as the primary measure of the effectiveness of the laws. Few studies have associated bicycle-related injuries with legislation, and of those found that did, only six used state- or nation-wide hospital admissions or discharge data that captured outcomes for the majority of injured bicyclists in a population (*1-6*). Furthermore, of these six studies, only three analysed more than two years of post-legislation data (*2*, *5*, *6*), two of which used the same data source (*5*, *6*), and none examined outcomes of helmet laws in the United States, which has a much larger population of bicyclists to study compared with other countries with helmet legislation.

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

The objective of this study was to determine whether the bicycle safety helmet legislation in California was associated with statistically significant reductions in head injuries among bicyclists. The study used ten years of patient discharge records from all hospitals in California, from 1991 through 2000, to examine the relationship between the 1994 law and bicycle-related non-fatal injuries. There were 44,069 cases in total and each of them represented a non-fatal injury event for a bicyclist. Available data included seven variables: year, age, injury type, cause, county of residence, race/ethnicity, and sex; helmet use, however, is unknown. Two age groups, two time periods, and three injury types were defined for analysis. The study cases were young bicyclists, 17 years of age and under, who were required to use helmets; the controls were adults who were not so required. These two age 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 below the neck (*Other*).

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, e.g., bicycle distance travelled, was not available, the proportion of each of the three injury types to the total number of injuries per time period was used as the study outcome measure. It was assumed that the use of proportions would control for major changes in exposure due to annual variations of bicycle use in the population and, therefore, be more suitable than other outcome measures, such as population-based normalised injury rates, that could not address this problem of lack of exposure data. The relative proportions were expected to be independent of exposure and remain reasonably constant for both age groups unless an intervention, such as a 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 a comparison of 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 proportion of injury type outcome before and after the legislation for the two age groups while accounting for the other variables.

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. found that bicycle riders wearing helmets had 85% and 88% reductions in their risks of head and brain injuries, respectively (*7*). In an Australian study of injured bicyclists in two Victoria hospitals, McDermott, et al. found that bicycle helmets reduced the number of head injuries by 45% (*8*). The findings of these two studies are not directly comparable because of differences in injury classification and crash circumstances of the samples. Among studies of young bicyclists, British Columbia researchers reported that head and face injuries were 1.5 times more common among youths who did not use safety helmets than among those who did (*9*), 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 (*10*).

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 and facial injuries in different age groups. 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 (*11*). 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 credited with providing significant protection for the upper and mid face but they did not appear to offer any protection to the lower face (*12*).

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. reviewed 16 studies using 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% (*13*). In a review of 5 case-control studies, D. Thompson, et al. had similar conclusions: helmets provided 69% reductions in risk of head and brain injuries (*14*).

Bicycle Safety Helmet Legislation

Several reviews on the prevention of unintentional injuries, such as those experienced by bicyclists, recognised that legislation is an effective modifier of the safety behaviours of large segments of the population (*15-18*). 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 safety helmet use are considered relatively easy to implement as well as cost-effective (*19*) and helmet wearing is not an unusual hardship on individuals (*16*).

Provisions for education and subsidy programs, as well as enforcement and penalties for non-compliance, are optional parts of any bicycle safety helmet legislation. Researchers have found that bicycle helmet laws without any of these provisions are not as effective in increasing helmet use as ones combined with various supporting elements (*15*, *18*, *20-25*). 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 (*21*).

An abundance of research from Australia, Canada, New Zealand, and the United States illustrate the various effects of bicycle safety helmet legislation. Overall, legislation has been credited with increasing helmet use among bicyclists (*22*, *23*, *26-28*). 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 suggests that the effects of bicycle safety helmet laws on helmet use are dependent on many other supporting factors. Bicycle safety education and public information campaigns promoting the benefits of helmet use and the hazards of head injuries in bicycle crashes introduced a strong motivation for compliance with legislation (*29*). Positive attitudes toward bicycle safety helmets and public acceptance of a helmet law also contributed to compliance (*30*, *31*). In addition, an active enforcement and penalty system (*32*, *33*), on-going education (*22*, *23*), and subsidies for the purchase of helmets (*24*, *32*) 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 (*1-3*, *34*, *35*). Some of them, however, used incomplete data sources such as police reports or insurance claims, which tend to be biased towards motor vehicle-related crashes, leaving out many non-motor vehicle cases. Although data on the amount of bicycle travel (exposure) are scarce, two Australian studies have found an association between bicycle helmet legislation and reduction in bicycling activities (*29*, *36*), an undesirable side effect reflecting loss of some of the benefits of bicycling. A Canadian study, however, found contradicting results (*37*). Furthermore, most studies used data from within 3 years of the post-legislation period and few have examined the long-term effects of helmet laws. More research, therefore, is 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 account for the benefits and costs accurately.

DATA AND ANALYSIS

The data used in this study are disaggregate hospital discharge records of bicycle-related non-fatal injuries for the years 1991 through 2000 from all public hospitals in California. Two approaches, one aggregate and one disaggregate, were used to analyse the data.

California Bicycle-Related Non-Fatal Injury Data

Hospital discharge 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. No record was available to indicate whether the victims in these cases used a bicycle safety helmet. Cause was categorised as motor vehicle- (MV) or non-MV-related. The county of residence variable was categorised as urban or non-urban, to indicate the context. Urban counties were the most densely populated and together they represent the four largest population centres in California: Los Angeles, San Francisco, San Diego, and Sacramento. Of course the population density varies greatly within a county and data were only available for place of residence, thus, it was not possible to define conditions at the site. Race/ethnicity groups included Asian, Black, Hispanic, White, and other. Table 1 summarises the number of cases available for analysis for each variable.

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 described the part associated with 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*.

No data were available to indicate the level of enforcement of the helmet legislation. This, combined with the absence of compliance data, means that the intervention analysed here was only the legislation. Given these data limitations, the only way to understand the effect of the helmet law is through the injury outcomes. The path to those outcomes, which is probably affected by both enforcement and compliance, cannot be known.

Aggregate Data Analysis – Pearson Chi-Squared Test for Independence and Odds Ratios

An aggregate approach was first taken to test whether there were any statistically significant changes among the proportions of injury types before and after the legislation for the *Youth* and *Adult* groups. 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 (*38*), which in this case were injury type and time. 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 hypothesis 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, $P < 0.001$). 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 pre- and post-legislation periods. This result, however, could not reveal how the proportions changed. To accomplish this, the Odds Ratio (OR) values were computed. OR is a common measure of association for two variables, which in this case were also injury type and time. In the context of this study, an OR is defined as one proportion divided by another, such as the proportion of *Head-TBI* of all bicycle injuries in the post-legislation period divided by the corresponding proportion in the pre-legislation period. As such, the OR compares the denominator to the numerator, which in this case is a comparison of outcomes in the pre- and post-legislation periods. Computed this way, the OR is unaffected by changes in the amount of bicycling between the two periods; that is, the OR is independent of exposure. Table 2 summarises the results of the OR calculations, which included the 99.0% confidence intervals (CI), for both age groups.

Table 2 shows that there was a statistically significant reduction, 18.2% (99.0% CI: 11.5%-24.3%), in the proportion of *Head-TBI* 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, which is to be expected since the injury proportions must add to 1.0. At the same time, there was no significant change for *Head-Other* injuries since the CI for this OR included 1.0. For the *Adult* group, the table confirms the results from the Pearson chi-square test result; there were no statistically significant changes for any type of injuries between the pre- and post-legislation periods.

Pooled Disaggregate Data Analysis – Multinomial Logit Models

A pooled disaggregate data analysis method was used to examine whether different age groups within the *Youth* category experienced similar associations with the bicycle safety helmet legislation. Furthermore, this approach supported exploration of whether and how other variables were associated with changes in *Head-TBI*.

An 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 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; the outcome alternatives in this application were the three defined injury types. Five models were developed and the explanatory variables included in each one were age, year (to reflect pre- and post legislation periods), cause, area type, race/ethnicity, and sex, where each variable is composed of two or more mutually exclusive and collectively exhaustive categories. The first model explored two-way interactions between the age and year variables. The *Youth* category was subdivided into four subgroups and the aim was to investigate how the outcome likelihood varied between different bicyclists subjected to the same helmet law, across the pre- and post-legislation periods, while accounting for *Adult* bicyclists and the other variables. The other models introduced three-way interactions of age and year with the other four variables, with each interaction in a separate model. These three-way interactions would reveal how cause, area type, race/ethnicity, and sex were associated with each type of injury outcome for *Youth* in relation to the legislation and compared with *Adult*. The results of these models are independent of exposure and were used to estimate the proportions of each injury type for different variable categories. These estimates, along with the 95% CI, are presented in Figures 1 to 5.

Figure 1 shows that, controlling for other variables and relative to the reference *Adult* group, all subgroups within the *Youth* category had statistically significant decreases in the proportion of *Head-TBI* after the legislation went into effect. The two youngest groups, 0-4 and 5-9 years, had the greatest changes, decreases of 9.2% (95% CI: 4.9%-13.5%) and 8.2% (6.1%-10.3%), respectively, while the two other groups were associated with smaller decreases of less than 5%. There were no significant changes to the proportions of *Head-Other* injuries for all age groups across the two periods except for the 14-17 years group, which had a small increase of 1.9% (0.6%-3.2%). On the other hand, the oldest group was the only one that did not have a significant change in the proportion of *Other* injuries while the other three groups had increases corresponding to the change in *Head-TBI*.

In Figure 2, the similarly sloped lines show that the MV- and Non-MV-related groups experienced almost identical levels of reductions in *Head-TBI* cases and increases in *Other* injuries; there was no change for the *Head-Other* injuries. In contrast, Figure 3 revealed differences between the two area types. Residents of non-urban counties had a drop of 5.2% (3.2%-7.3%) in *Head-TBI* and a corresponding increase of 5.0% (2.9%-7.1%) in *Other* injuries associated with the legislation. On the other hand, urban residents had significant increases in both types of head injuries, 3.2% (1.7%-4.7%) for *Head-TBI* and 2.3% (1.5%-3.1%) for *Head-Other*, and a corresponding decrease in *Other* injuries, 5.5% (3.9%-7.1%). Whites, Asians, and Hispanics had significant decreases in *Head-TBI* and increases in *Other* injuries (Figure 4), while Blacks and others had no significant changes associated with the helmet law. Similarly, in Figure 5, males had a significant reduction in *Head-TBI* and a corresponding increase in *Other* but females had no significant changes.

DISCUSSION

The Pearson chi-squared test and the OR calculations showed that there was a statistically significant decrease in the proportion of *Youth* bicyclists with *Head-TBI* as their primary diagnosis when comparing the post- with the pre-legislation period. There was a corresponding increase in the proportion of *Other* injuries and an insignificant increase in *Head-Other* injuries. On the other hand, there was no statistically significant change in the proportions among the injury outcomes for the *Adult* patients, the group not directly affected by the helmet use legislation. This comparison and the results of previous research showing that the use of bicycle safety helmets reduces the incidence of *Head-TBI* (*7*, *10*, *11*) suggest that one reason, if not the main reason, for the decrease in the proportion of injured *Youth* bicyclists with *Head-TBI* across the pre- and post-legislation periods is the enactment of the helmet law. There is, however, no helmet use data to substantiate whether this law resulted in a direct effect on this behaviour.

If the bicycle safety helmet legislation did have an effect on decreasing the proportion of *Head-TBI* among *Youth* riders, then one may question why a decrease was not also found in the proportion of *Head-Other* injuries for this group. Furthermore, even if the helmet law had no protective effects on *Head-Other* injuries, why did the proportion 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*.

The *Head-Other* term refers to the EPIC definition of the “Other head, face, and neck” body region and this 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. 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 no protection was found for the lower face or neck (*12*). It is, therefore, reasonable that the decrease in the proportion of *Head-TBI* 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 proportion of *Head-Other* injuries among *Youth* bicyclists might have increased instead of remaining constant, one must consider what could happen when the proportion of *Head-TBI* decrease. For 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 proportions 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* cases were prevented and these five bicyclists escaped hospitalisation all together, and the number of other bicycle-related injuries remained the same, then the respective proportions for this post-legislation year would be 21.0%, 10.5%, and 68.4%. Cases dropping out of the dataset because *Head-TBI* cases were prevented could cause the proportions of other outcomes to increase even though the number of *Head-Other* and *Other* injuries did not increase. If these five bicyclists were protected from *Head-TBI* but were not lucky enough to escape hospitalisation, then they would each be classified in either of the other two outcomes. The proportion of *Head-TBI* would still drop, to 20%, but the other two proportions could only remain the same or increase. If bicycle safety helmet legislation had absolutely no protective effects on *Head-Other* injuries, then the proportion 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 proportion of this injury type to have remained the same, increased, or decreased.

It is important to note that the dataset used in this study does not include fatal injury cases, for reasons explained above. The reduction in *Head-TBI* among *Youth* bicyclists found in this study may, in fact, be conservative because most bicycle fatalities result from head trauma (*39*) and the helmet legislation may have prevented some fatal injuries. The cases of bicyclists who escaped death but still required hospitalisation would have been transferred to this non-fatal injury dataset and may have offset the reduction in *Head-TBI*.

The disaggregate analysis explored the relationships between the likelihood of each injury type and the other variables. One MNL model tested the two-way interaction between age and year of injury, and the results shown in Figure 1 confirmed the findings of the aggregate analysis. All *Youth* bicyclists had a decrease in the likelihood of *Head-TBI* injuries, but this change 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 showed the smallest decrease. This distribution 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 the least affected by legislative interventions (*30*,*31*). Furthermore, peer pressure was found to be an important factor for not wearing helmets (*40*,*41*) and it would be reasonable to assume that the older *Youth* riders were subjected to more of it. For *Head-Other* injuries, the proportions remained unchanged for all *Youth* subgroups in the post-legislation period except for those who were 14-17 years. It is possible that for this subgroup, more *Head-TBI* cases were transferred to *Head-Other* in comparison to the other subgroups but it is unclear why this may be so, particularly when it only had a small corresponding decrease in the proportion of *Head-TBI*.

The other MNL models examined three-way interactions that combined age and year with the cause, area type, sex, and race/ethnicity variables. For the cause variable, the legislation was associated with similar decreases in the proportion of *Head-TBI* for both MV-related and non-MV-related incidents among *Youth* bicyclists. Figure 2 also showed that the proportion of *Head-TBI* was significantly higher for the MV category, which was expected since encounters with MV tend to be more intense. As for the area type variable, it is important to keep in mind that this classification refers to the county of residence for the injured bicyclists, which is not necessarily the same one where the injury occurred. It is, however, likely that, particularly among *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 has shown that young riders spend most of their bicycle riding time on neighbourhood streets, sidewalks, and playground (*42*). The results in Figure 3 showed that the proportion of *Head-TBI* decreased for non-urban residents but increased for urban ones. Furthermore, *Head-Other* injuries remained unchanged for the first category but increased for the latter. One possible explanation for these differences is that non-urban residents may have had higher helmet-wearing rates after the legislation than those who lived in the urban counties. Another possible reason is that the urban bicycling environment became more unsafe during the period after the legislation was enacted and that caused more serious injuries involving the head. Both of these reasons, however, are speculative. Furthermore, since counties are large and can exhibit a wide range of localized densities, it is not possible to draw strong inferences about the effects of this variable.

The last two models showed results that are more difficult to explain. For the race/ethnicity variable, the legislation was associated with decreases in the proportion of *Head-TBI* for all categories of *Youth* riders except for Black and other. In addition, it appeared that the association with the legislation was particularly strong for Asians and Hispanics. Possible reasons for the differences in changes for the different races/ethnicities are different social/cultural attitudes towards obeying the law and different socio-economic conditions. Research shows that demographic and economic factors are significant determinants for at least one type of bicycle collisions, those with motor vehicles (*43*), and it may be possible that bicycle safety helmets are, on average, more of a financial burden for Black and other racial groups. Resources for encouraging helmet use may also be, for whatever reasons, more accessible and effective in the Asian and Hispanic communities. Finally, for the sex variable, there was a significant decrease in the proportion of *Head-TBI* for males but the proportion was unchanged 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 (*42*) 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 (*42*). For some reason, male bicyclists tend to be more injury prone. This difference, however, does not adequately explain the decrease in the proportion of *Head-TBI* for males but not for females. Perhaps 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. It is also possible that even a small increase in the use of helmets by males produced a disproportionately large positive effective because of their risk-prone riding habits.

CONCLUSIONS

Bicycle safety helmet legislation in California is associated with significant reductions in traumatic brain injuries in aggregate, and for selected groups. This finding is independent of any assumptions about the level of compliance and enforcement of this law as well as any changes in bicycle use (i.e., exposure).

The bicycle safety helmet legislation in California was found to be associated with a reduction of 18.2% (99% confidence interval: 11.5%-24.3%) in the proportion of traumatic brain injuries among injured youth bicyclists 17 years of age and under, who were subjected to the law. The proportions 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, as expected. 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 0-9 years, had the greatest decrease in the proportion having traumatic brain injuries as the primary injury diagnosis. Teenagers from 14 through 17 years, on the other hand, had a small decrease in the proportion of this injury type as well as an increase the proportion of other head, face, and neck injuries.

The reduction in the proportion of traumatic brain injuries associated with the helmet law for youth bicyclists under 18 years was the same for motor vehicle and non-motor vehicle-related incidents. There was a reduction for residents of non-urban counties but not for urban ones. 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 Whites, Asians, and Hispanics, but not Blacks and others.

RECOMMENDATIONS

Continued advocacy of bicycle helmet use legislation seems warranted based on injury outcome measures. Additional research may help target efforts to promote the use of bicycle helmets. The sex and race/ethnicity of an individual may be associated with many socio-economic and behavioural factors that help explain injury mechanisms and determine the most appropriate injury prevention strategies. In this study, different categories within these variables were found to have been differently associated with outcomes of the bicycle safety helmet legislation. It is worthwhile to pursue more detailed investigations of the causes for these differences to understand how different segments of the bicycling populations might be targeted for helmet use promotion in conjunction with legislation mandating such use.

Future research should also look for any "carry-over" effects among bicyclists who were subjected to bicycle safety helmet legislation in their youth. Existence of a significant carryover effect would amplify the benefits of age-specific helmet use laws.

The lack of exposure data and reliable methods to estimate patterns of bicycling activities is a significant limitation on bicycle safety research. In addition, data on both enforcement and compliance, in combination with injury outcomes, would provide a stronger basis for understanding the effectiveness of such legislation and ways to enhance it.

REFERENCES

1 Cameron, Maxwell H, A Peter Vulcan, Caroline F Finch, and Stuart V Newstead. Mandatory bicycle helmet use following a decade of helmet promotion in Victoria, Australia – an evaluation. Accident Analysis and Prevention 1994; 26(3): 325-337.

2 Hendrie, Delia, Matthew Legge, Diana Rosman, and Carol Kirov. An economic evaluation of the mandatory bicycle helmet legislation in Western Australia. In 1999 Insurance Commission of Western Australia, Conference on Road Safety: Speakers' Papers. Perth, Western Australia: Insurance Commission of Western Australia, 26 Nov 1999, 29-45.

3 Macpherson, Alison K, Teresa M To, Colin Macarthur, Mary L Chipman, James G Wright, and Patricia C Parkin. Impact of mandatory helmet legislation on bicycle-related head injuries in children: a population-based study. Pediatrics Nov 2002; 110(5): e60.

4 Marshall, J, and M White. Evaluation of the compulsory helmet wearing legislation for bicyclists in South Australia. Office of Road Safety, South Australian Department of Transport, Office of Road Safety Report Series, Aug 1994.

5 Povey, LJ, WJ Frith, and PG Graham. Cycle helmet effectiveness in New Zealand. Accident Analysis and Prevention 1999; 31: 763-770.

6 Scuffham, Paul A, Jonathan Alsop, Colin Cryer, and John D Langley. Head injuries to bicyclists and the New Zealand bicycle helmet law. Accident Analysis and Prevention Jul 2000; 32(4): 565-573.

7 Thompson, Robert S, Frederick P Rivara, and Diane C Thompson. A case-study control of the effectiveness of bicycle safety helmets. New England Journal of Medicine 25 May 1989; 320(21): 1361-1367.

8 McDermott, Frank T, John C Lane, GA Brazenor, and Elizabeth A Debney. The effectiveness of bicyclist helmets: a study of 1710 casualties. The Journal of Trauma June 1993; 34(6): 834-845.

9 Linn, Shai, D Smith, and S Sheps of the Canadian hospitals injury reporting and prevention program (CHIRPP). Epidemiology of bicycle injury, head injury, and helmet use among children in British Columbia: a five year descriptive study. Injury Prevention 1998; 4: 122-125.

10 Thomas, Steven, Caroline Action, James Nixon, Diane Battistutta, W Robert Pitt, and Ronald Clark. Effectiveness of bicycle helmets in preventing head injury in children: case-control study. British Medical Journal 15 Jan 1994; 308: 173-176.

11 Thompson, Diane C, Frederick P Rivara, and Robert S Thompson. Effectiveness of bicycle safety helmets in preventing head injuries: a case-study study. *Journal of American Medical Association* 25 Dec 1996a; 276(24): 1968-1973.

12 Thompson, Diane C, Martha E Nunn, Robert S Thompson, and Frederick P Rivara. Effectiveness of bicycle safety helmets in preventing serious facial injury. *Journal of the American Medical Association* 25 Dec 1996b; 276(24): 1974-1975.

13 Attewell, Robyn G, Kathryn Glase, and Michael McFadden. Bicycle helmet efficacy: a meta-analysis. *Accident Analysis and Prevention* 2001; 33: 345-352.

14 Thompson, Diane C, Frederick P Rivara, and Robert S Thompson. Helmets for preventing head and facial injuries in bicyclists. The Cochrane Database of Systematic Reviews 2002; 4: CD001855.
15 Dowswell, Therese, EML Towner, G Simpson, and SN Jarvis. Preventing childhood unintentional injuries – what works? A literature review. Injury Prevention June 1996; 2(2): 140-149.
16 Graitcer, Philip L, Arthur L Kellermann, and Tom Christoffel. A review of education and legislative strategies to promote bicycle helmets. Injury Prevention 1995; 1: 122-129.
17 Rivara, Frederick P, Diane C Thompson, Matthew Q Patterson, and Robert S Thompson. Prevention of bicycle-related injuries: helmets, education, and legislation. Annual Review of Public Health 1998; 19: 293-318.
18 Schieber, Richard A, Julie Gilchrist, and David A Sleet. Legislative and regulatory strategies to reduce childhood unintentional injuries. The Future of Children Spring-Summer 2000; 10(1): 111-136.
19 Hatziandreu, Evi J, Jeffrey J Sacks, Ruth Brown, William R Taylor, Mark L Rosenberg, and John D Graham. The cost effectiveness of three programs to increase use of bicycle helmets among children. Public Health Reports May-June 1995; 110 (3): 251-259.
20 Abularrage, Joseph J, Arthur J Deluca, and Christopher J Abularrage. Effect of education and legislation on bicycle helmet use in a multiracial population. Archives of Pediatric and Adolescent Medicine Jan 1997; 151(1): 41-44.
21 Borgialli, DA. Bicycle helmet laws: a current perspective. Journal of the American Osteopathic Association July 1997; 97(7): 399-402.
22 Coté, Timothy R, Jeffrey J Sacks, Deborah A Lambert-Huber, Andrew L Dannenberg, Macie-Jo Kresnow, Cynthia M Lipsitz, and Ellen R. Schmidt. Bicycle helmet use among Maryland children: effect of legislation and education. Pediatrics June 1992; 89(6): 1216-1220.
23 Dannenberg, Andrew L, Andrea C Gielen, Peter L Beilenson, Modena H Wilson, and Alain Joffe. Bicycle helmet laws and educational campaigns: an evaluation of strategies to increase children's helmet use. *American Journal of Public Health* May 1993; 83(5): 667-674.
24 Macknin, Michael L, and Sharon VanderBrug Medendorp. Association between bicycle helmet legislation, bicycle safety education, and use of bicycle helmets in children. *Archives of Pediatric and Adolescent Medicine* Mar 1994: 148(3): 255-259.
25 Rodgers, Gregory B. Effects of state helmet laws on bicycle helmet use by children and adolescents. *Injury Prevention* 2002; 8: 42-46.
26 Ni, Hanyu, Jeffrey J Sacks, Lita Curtis, Paul R Cieslak, and Katrina Hedberg. Evaluation of a statewide bicycle helmet law via multiple measures of helmet use. *Archives of Pediatrics and Adolescent Medicine* Jan 1997; 151(1): 59-65.
27 Rodgers, Gregory B. Effects of state helmet laws on bicycle helmet use by children and adolescents. *Injury Prevention* 2002; 8: 42-46.
28 Schieber, Richard A, Marcie-Jo Kresnow, Jeffrey J Sacks, Edwin E Pledger, Joann M O'Neill, and Kathleen E Toomey. Effect of a state law on reported bicycle helmet ownership and use. *Archives Pediatric Adolescent Medicine* July 1996; 150(7): 707-712.
29 Finch, Caroline F, Lorna Heiman, and Dina Neiger. *Bicycle use and helmet wearing rates in Melbourne, 1987 to 1992: the influence of the helmet wearing law*. Report 45. Victoria, Australia: Accident Research Centre, Monash University, Feb 1993.
30 Finch, Caroline F. Teenagers' attitudes towards bicycle helmets three years after the introduction of mandatory wearing. *Injury Prevention* June 1996; 2(2): 126-130.
31 Heathcote, Bruce, and Gavin Maisey. *Bicycle use and attitudes to the helmet wearing law*. Report no. TB94-1. Perth, Australia: Traffic Board of Western Australia, May 1994.
32 Gilchrist, Julie, Richard A Schieber, Steven Leadbetter, and Stephen C Davidson. Police enforcement as part of a comprehensive bicycle helmet program. *Pediatrics* July 2000; 106(1): 6-9.
33 King, Mark, and Graham Fraine. Bicycle helmet legislation and enforcement in Queensland 1991 to 1993: effect on helmet wearing and crashes. In *Proceedings: 1994 Australian Pedestrian and Bicyclist Safety and Travel Workshop, Melbourne, Australia*, ed. David Andreassen and Geoff Rose. Victoria, Australia: Australian Road Research Board, Transport Research, 177-190, 1994.

34 Grant, Darren and Stephen M Rutner. The effect of bicycle helmet legislation on bicycling fatalities (Working Paper). In The University of Texas at Arlington, Department of Economics – Working Paper Archive home page [online]. 2002 [cited 18 Mar 2003] <http://economics.uta.edu/wpapers.shtml>.

35 LeBlanc, John C, Tricia L Beattie, and Christopher Culligan. Effect of legislation on the use of bicycle helmets. *Canadian Medical Association Journal* 2002; 166(5): 592-595.

36 Smith, Nariida C., and Frank W. Milthorpe. Bicycle helmet wearing in New South Wales after legislative mandate. In *Proceedings: 1994 Australian Pedestrian and Bicyclist Safety and Travel Workshop, Melbourne, Australia*, ed. David Andreassen and Geoff Rose. Victoria, Australia: Australian Road Research Board, Transport Research, 1994, 153-164.

37 Macpherson, Alison K, Patricia C Parkin, and Teresa M To. Mandatory helmet legislation and children's exposure to cycling. *Injury Prevention* 2001; 7: 228-230.

38 Walpole, Ronald E, Raymond H Myers, and Sharon L Myers. *Probability and statistics for engineers and scientists*. Upper Saddle River, NJ: Prentice Hall, 1998.

39 Sacks, Jeffrey J, Patricia Holmgreen, Suzanne M Smith, and Daniel M Sosin. Bicycle-associated head injuries and deaths in the United States from 1984 through 1988: how many are preventable? *Journal of American Medical Association* 4 Dec 1991; 266(21): 3016-3018.

40 Cryer, P Colin, Jeremy Cole, Leslie L Davidson, Mohammed Rahman, Vivian Ching, and Janet B Goodall. Rates of, and the factors affecting, bicycle helmet use among secondary schoolchildren in East Sussex and Kent. *Injury Prevention* 1998; 4: 106-110.

41 Lajunen, Timo, and Mikko Räsänen. Why teenagers owning a bicycle helmet do not use their helmets. *Journal of Safety Research* 2001; 32: 323-332.

42 Rodgers, Gregory B. Bicycle and bicycle helmet use patterns in the United States in 1998. *Journal of Safety Research* 2000; 31(3): 149-158.

43 Epperson, Bruce. Demographic and economic characteristics of bicyclists involved in bicycle-motor vehicle accidents. *Transportation Research Record 1502* 1995; 58-64.

LIST OF TABLES AND FIGURES

Tables

Figures

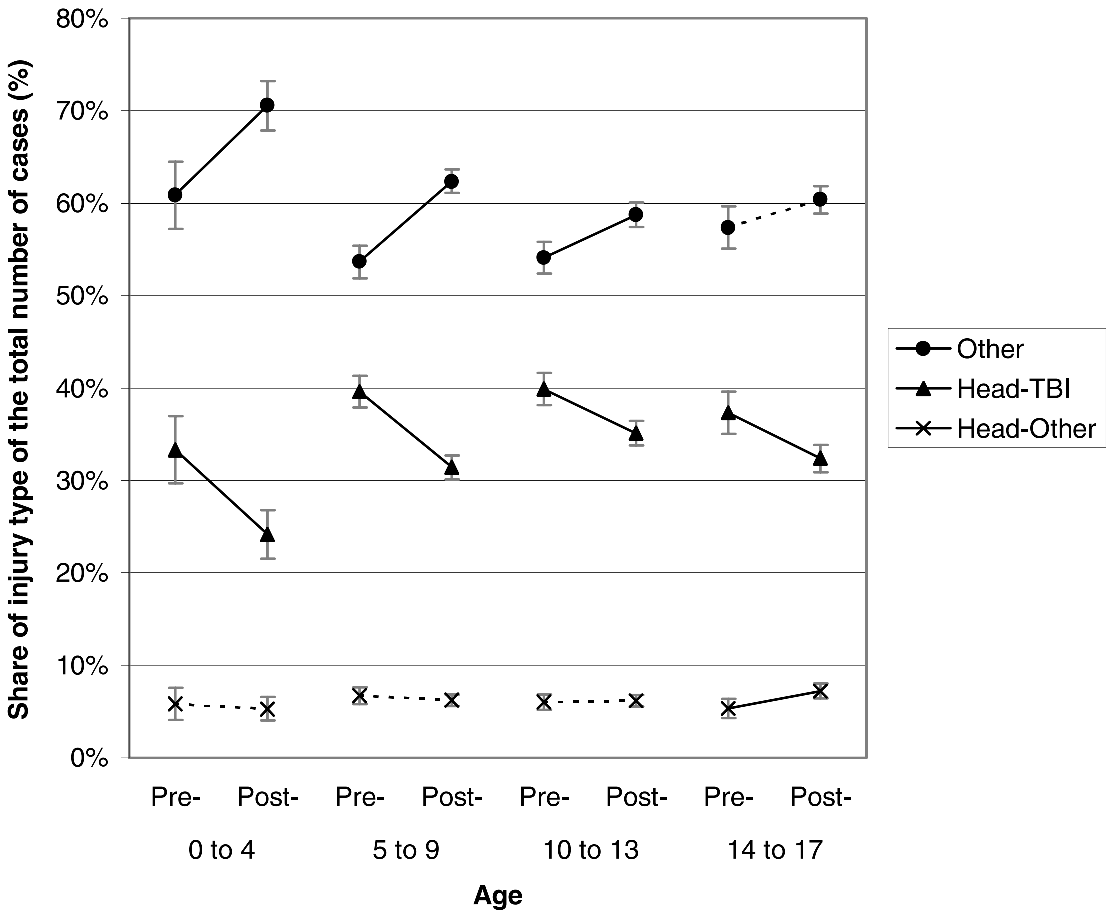
TABLE 1 Bicycle-Related Non-Fatal Injuries in California – Number of Cases by Period, Age, Injury Type, and Other Variables (total = 44,069 cases)

Period	**Pre-legislation**, 1991-1993						**Post-legislation**, 1994-2000					
	13,717						30,352					
Age	***Youth***, 0-17			***Adult***, 18+			***Youth***, 0-17			***Adult***, 18+		
	6,229			7,488			11,485			18,867		
Injury type	***Head-TBI***	***Head-Other***	***Other***	***Head-TBI***	***Head-Other***	***Other***	***Head-TBI***	***Head-Other***	***Other***	***Head-TBI***	***Head-Other***	***Other***
	2,037	442	3,750	1,521	594	5,373	3,073	879	7,533	3,865	1,572	13,430
Cause												
MV	703	142	1,088	486	175	1,342	1,046	281	1,866	1,448	501	3,580
Non-MV	1,334	300	2,662	1,035	419	4,031	2,027	598	5,667	2,417	1,071	9,850
Area type												
Urban	1,276	307	2,381	1,066	441	3,838	1,925	615	4,698	2,809	1,178	9,180
Non-urban	761	135	1,369	455	153	1,535	1,148	264	2,835	1,056	394	4,250
Race/ethnicity												
White	1,286	266	2,050	1,054	405	4,081	1,641	440	3,805	2,486	964	9,467
Asian	105	20	183	65	26	162	130	24	306	155	51	422
Black	137	35	325	50	33	231	252	105	629	169	93	768
Hispanic	470	109	1,123	316	123	818	926	273	2,516	944	425	2,442
Other	39	12	69	36	7	81	124	37	277	111	39	331
Sex												
Male	1,634	339	2,992	1,239	490	4,111	2,471	740	6,115	3,197	1,328	10,778
Female	403	103	758	282	104	1,262	602	139	1,418	668	244	2,652
***Youth* sub-groups**												
0-4	129	33	324	not applicable			152	51	603	not applicable		
5-9	739	172	1,298				1,001	288	2,588			
10-13	765	158	1,332				1,143	289	2,469			
14-17	404	79	796				777	251	1,873			

TABLE 2 Odds Ratios of Bicycle-Related Non-Fatal Injuries in California – Proportions of the Total by Injury Types and Age for the Pre-legislation Period Compared with Corresponding Proportions for the Post-legislation Period

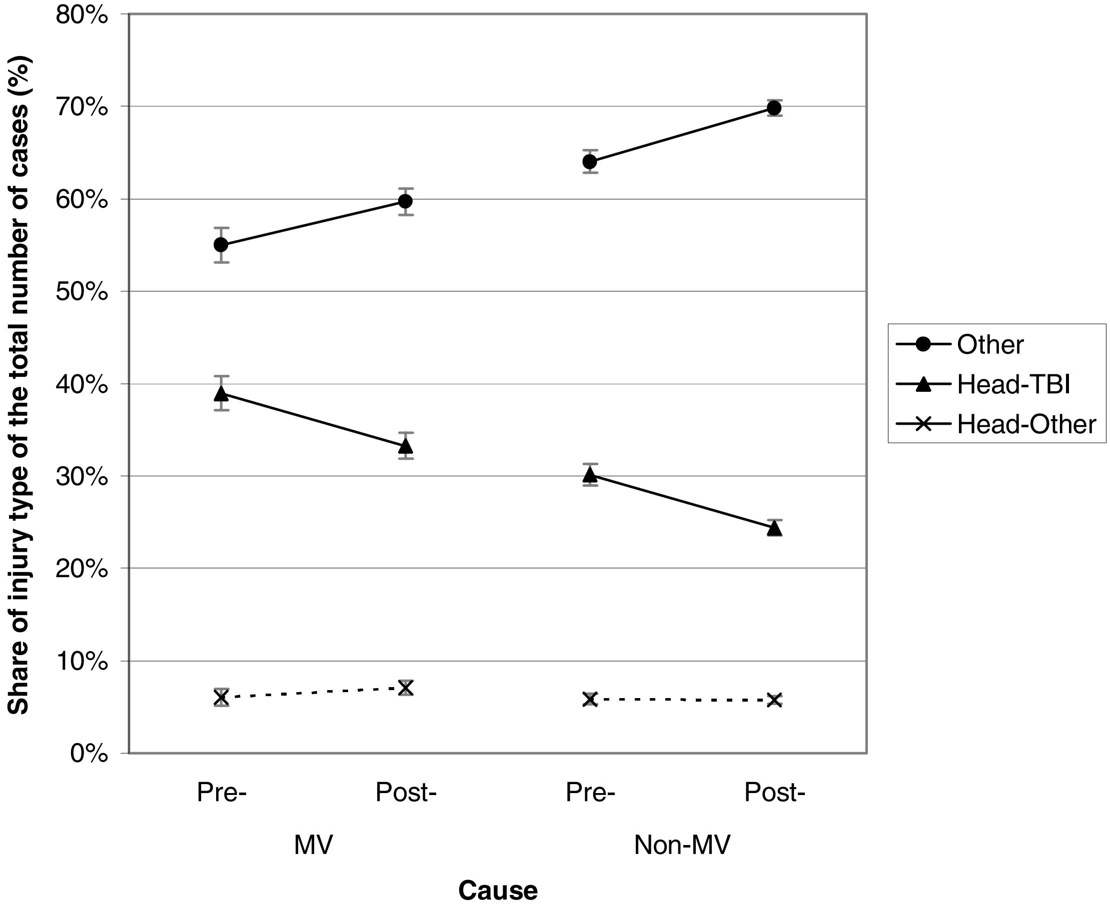
Age	Type of injuries	Pre-legislation, 1991-1993 [A]	Post-legislation, 1994-2000 [B]	Odds ratios [B/A]
Youth	***Head-TBI***	0.327 [(1)] (0.313-0.341) [(2)]	0.268 (0.258-0.277)	0.818 (0.757-0.885)
	Head-Other	0.0710 (0.0634-0.0785)	0.0765 (0.0708-0.0823)	1.08 (0.901-1.23)
	Other	0.602 (0.588-0.612)	0.656 (0.646-0.666)	1.09 (1.05-1.13)
Adult	***Head-TBI***	0.203 (0.192-0.214)	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* Youth *cases in this period for this injury type*
(2) 99.0% CI



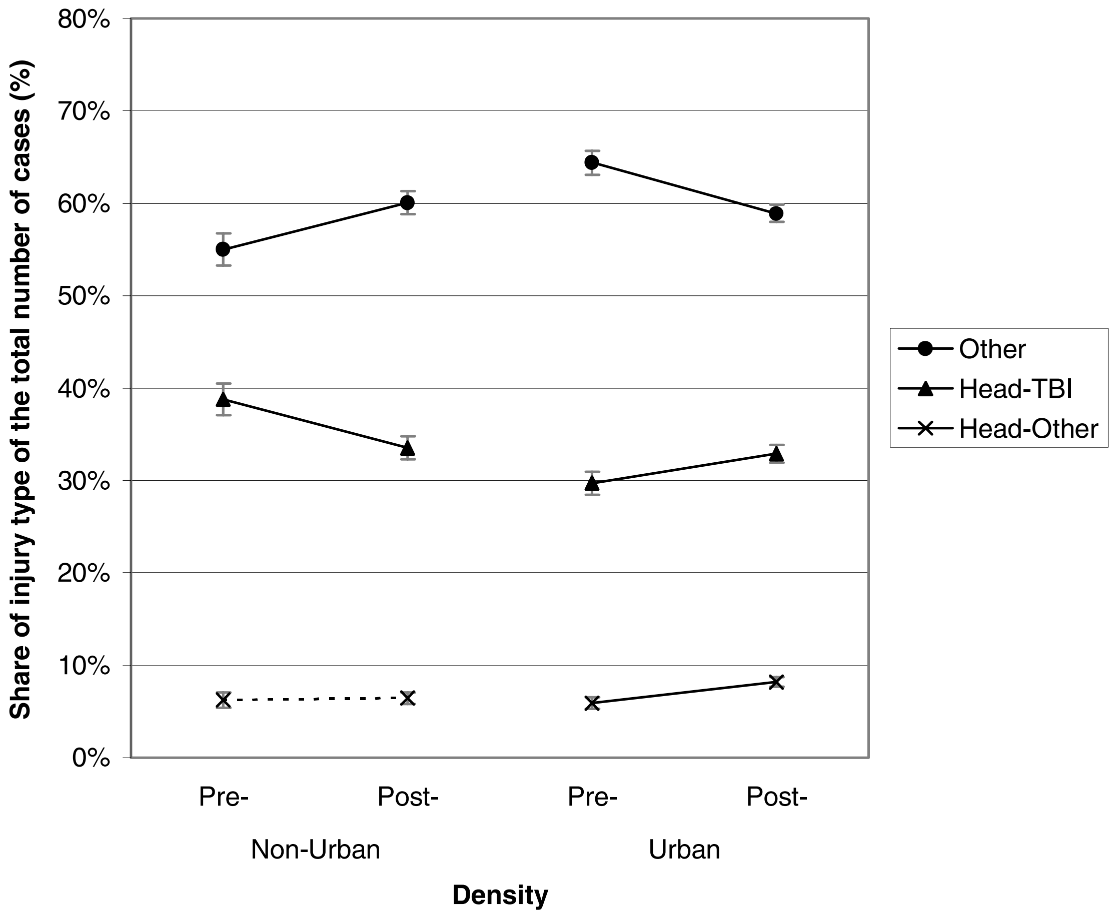
Notes: *(1) Error bars indicate 95.0% CI*
(2) Solid lines indicate statistically significant change between the two periods
(3) Broken lines indicate statistically insignificant change between the two periods

FIGURE 1 Changes in shares of bicycle-related non-fatal injury types in California for *Youth* – by Age, pre- vs. post-legislation period.



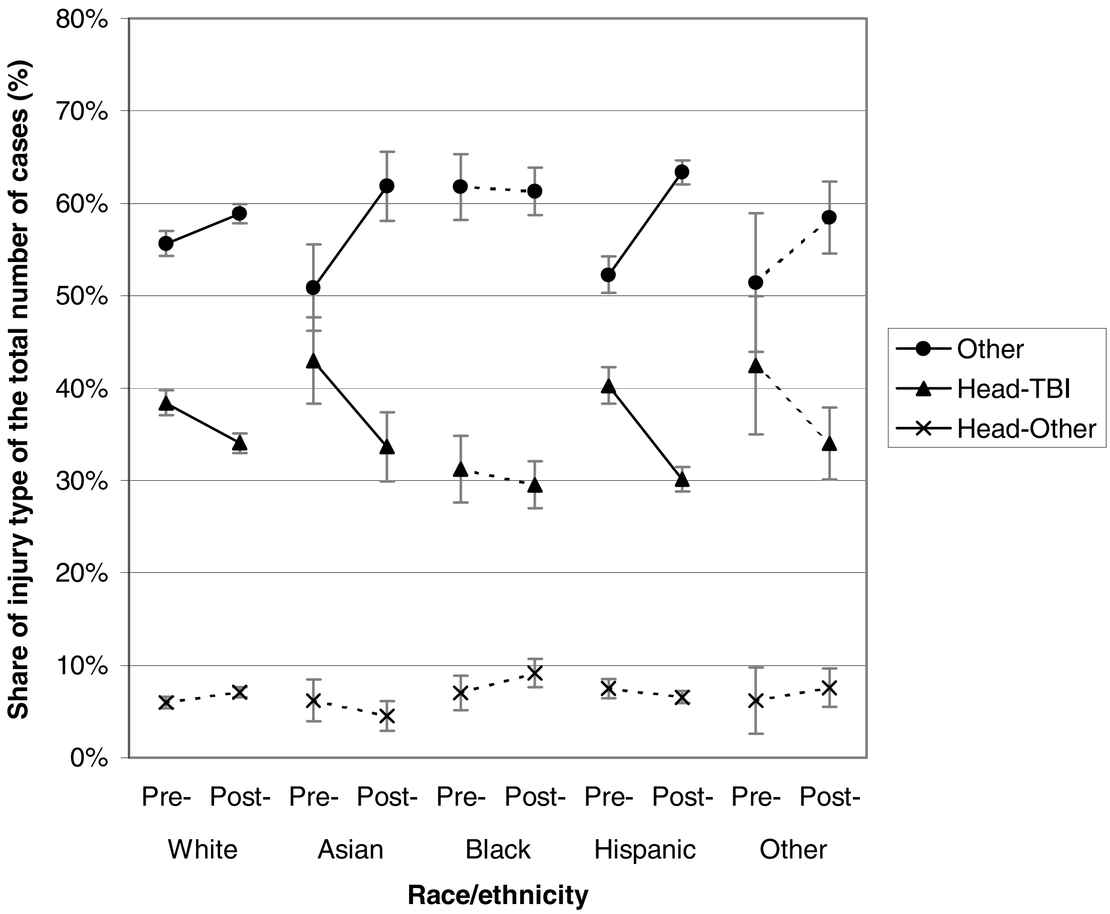
Notes: *(1) Error bars indicate 95.0% CI*
(2) Solid lines indicate statistically significant change between the two periods
(3) Broken lines indicate statistically insignificant change between the two periods

FIGURE 2 Changes in shares of bicycle-related non-fatal injury types in California for *Youth* – by Cause, pre- vs. post-legislation period.



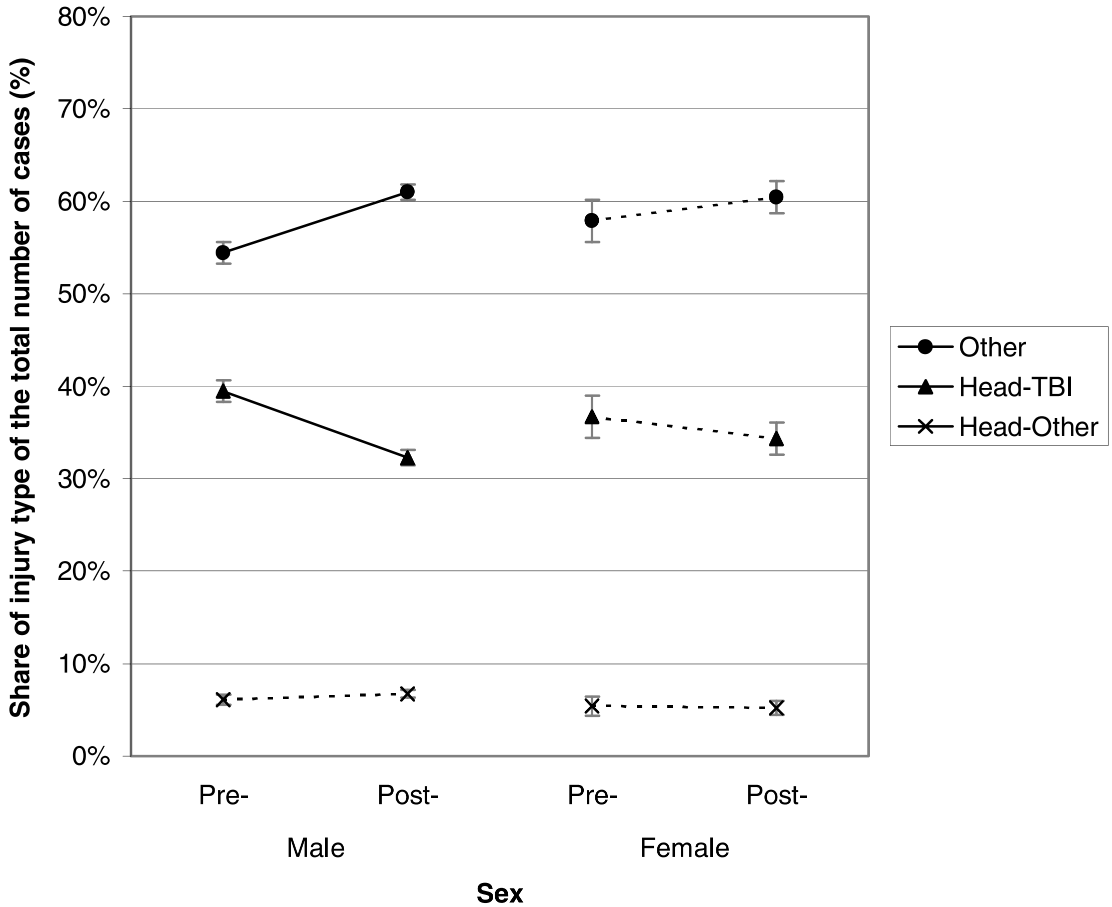
Notes: *(1) Error bars indicate 95.0% CI*
(2) Solid lines indicate statistically significant change between the two periods
(3) Broken lines indicate statistically insignificant change between the two periods

FIGURE 3 Changes in shares of bicycle-related non-fatal injury types in California for *Youth* – by Area type, pre- vs. post-legislation period.



Notes: (1) Error bars indicate 95.0% CI
(2) Solid lines indicate statistically significant change between the two periods
(3) Broken lines indicate statistically insignificant change between the two periods

FIGURE 4 Changes in shares of bicycle-related non-fatal injury types in California for *Youth* – by Race/ethnicity, pre- vs. post-legislation period.



Notes: *(1) Error bars indicate 95.0% CI*
(2) Solid lines indicate statistically significant change between the two periods
(3) Broken lines indicate statistically insignificant change between the two periods

FIGURE 5 Changes in shares of bicycle-related non-fatal injury types in California for *Youth* – by Sex, pre-vs. post-legislation period.