The Effectiveness of Motorcycle Helmets and Mandatory Helmet Laws

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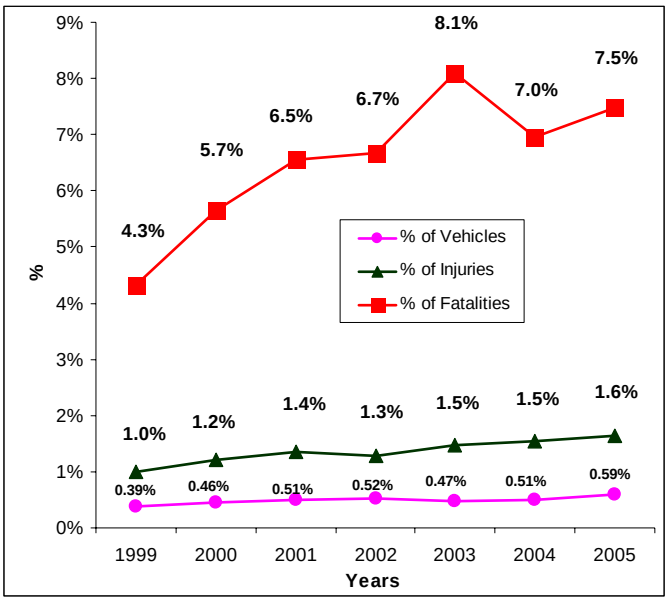
December 9, 2006

In the past 25 years there has been a large number of research studies published which address the effectiveness of mandatory helmet laws. Most of these studies have concluded that motorcycle helmets are effective in preventing fatal injuries. Nevertheless many states have no mandatory helmet laws and other states have repealed mandatory helmet laws. This article revisits the question of effectiveness of helmets versus the effectiveness of mandatory helmet laws and demonstrates the importance of properly defining the population at risk as the motorcycle riders in a crash. It is argued that fatalities and injuries should thus be normalized by the number of riders in crashes or the number of crashes rather than vehicle miles traveled or number of registrations. Louisiana crash data are used to assess the effectiveness of motorcycle helmets in crashes and the effectiveness of mandatory helmet laws. The Louisiana crash data which are unique in that the motorcycle helmet law was changed several times, in 1968, 1976, 1982, 1999 and 2004, show that helmets significantly reduce the risk of fatal and severe injury in crashes. Louisiana data also show that mandatory motorcycle helmet laws are effective in significantly reducing fatalities and severe injuries in motorcycle crashes. This article also summarizes the findings of other articles which use total number of riders in crashes or total number of crashes to normalize fatality and injury data and provides an estimate of the magnitude of the effectiveness of helmets in crashes and the effectiveness of mandatory helmet laws.

1. Introduction

Motorcycle deaths in the United States increased from 2,116 in 1997 to 4008 in 2004. While several studies, e.g. (Sosin 1992), (Watson, Zador et al. 1980), (Watson, Zador et al. 1980; Watson, Zador et al. 1981), (Evans and Frick 1988; Fleming and Becker 1992; Sarkar, Peek et al. 1995; Auman, Kufera et al. 2002) suggest that wearing a helmet reduces the risk of fatal injuries, mandatory helmet laws have not been implemented in all states and several states which have had mandatory helmet laws have repealed the law. Louisiana is one state in which motorcycle helmet laws have changed several times. Louisiana first adopted a motorcycle helmet law applicable to all riders in 1968 and amended it in 1976 to require helmet use only for riders under the age of 18. Then, in 1982, the state reenacted a universal helmet law again but it was amended effective August 1999 to require helmet use only by motorcycle operators and passengers under the age of 18 and riders 18 and older who did not have medical insurance coverage of at least $10,000. Following this change in the law, the motorcycle fatalities increased by 90% from 1999 to 2003. In 1999, motorcycles represented 0.39% of all vehicles in crashes, while motorcycle riders represented 4.3% of all the fatalities in crashes. In 2003, the year before the reinstatement of the mandatory helmet law in Louisiana, motorcycles represented 0.47% of all vehicles in crashes, while motorcycle fatalities represented 8.1% of all of the fatalities in crashes. Thus, while motorcycle rider fatalities were overrepresented by a factor of about 11 in 1999, this factor increased to 17 in 2003. Figure 1 depicts these statistics for the years 1999 to 2005. It is thus evident from the data that the motorcycle rider deaths as a percent of all vehicle deaths has been steadily increasing over the past five years.

Figure 1: Percentage of Motorcycle Fatalities vs. Percentage of Motorcycles among All Vehicle Crashes



Because of this large increase in fatalities, the state of Louisiana reenacted the mandatory helmet law again in September of 2004. Because of these changes in the law Louisiana provides a good example for a case study of the effectiveness of mandatory helmet laws. This paper presents a detailed analysis of the Louisiana crash data to determine if the repeal of the law contributed to an increase in motorcycle rider fatalities. Because there was a significant change in the crash report and an improved data quality in 1999, only data from 1999 to 2005 were used as the basis for this analysis.

There has been considerable research published which deals with the helmet use and mandatory helmet laws. Most of the research e.g. [(Watson, Zador et al. 1980), (Auman, Kufera et al. 2002), (Sosin, Sacks et al. 1990)] supports the argument that helmets are effective in preventing head injuries and thus mandatory helmet laws save lives. However, Stolzenberg et al. [(Stolzenberg 2003),(Stolzenberg 2003)] question the effectiveness of mandatory helmet laws in reducing motorcycle fatalities. There is also continued criticism of the published research from the Motorcycle Rider Lobby. This paper is organized as follows: section 2 gives a review of the literature and examines the reasons for the contradictory findings in the literature and for the continued criticism. Section 3 presents the methodology used in our analysis of motorcycle crashes. An

analysis of the Louisiana crash data follows. Section 4 summarizes the conclusions which can be drawn from the Louisiana data.

2. Literature Review

There are many published studies reporting on the effectiveness of helmets in preventing motorcycle head injuries. The studies reviewed in this article can be divided into two types. Several studies use in-patient hospital data to compare the injury and death rates of helmeted with non-helmeted motorcycle riders. Many other articles focus on the change in death rates for states which have instated or repealed mandatory helmet laws or compare the death and injury rates in states which have mandatory helmet laws with states which do not have mandatory helmet laws. The first type assesses the risk of being killed based on injured riders only. Since the severity of injury is often not reported in the study, the percentage of deaths varies considerably between the studies. The second type of study reported in this paper examines crash or injury data to determine the effect of mandatory helmet laws. Unfortunately, for these types of observational studies, it is difficult to account for all extraneous factors which may affect the number of crashes, injuries and death of motorcycle riders, specifically if the number of motorcycle registrations or vehicle miles traveled are used to normalize fatality or injury data.

Studies Comparing Injury of Riders by Helmet Use

Watson et al. (Watson, Zador et al. 1980) compared the deaths due to head injuries for motorcyclists who had worn helmets with those who had not worn helmets. Head injury deaths (202) were twice as frequent as deaths due to other causes (103) when helmets were not worn. When helmets were worn, the number of head-injury deaths (200) were similar to the number of deaths from other causes (212). The Chi-Square test for the dependency of type of injury (head/other) and wearing helmet/not wearing helmet indicate that it is statistically significant ($p<0.0001$).

Bachulis et al. (Bachulis, Sangster et al. 1988) studied the records of all motorcyclists admitted to Emanuel Hospital from January 1st, 1983, through May 31, 1987. They found a much higher percentage of deaths in non-helmeted riders than in helmeted riders. They found “23 deaths (9.7%) in the 235 non-helmeted patients

compared to 7 deaths (5.3%) in the 132 helmeted riders. “ They also report that almost half of the non-helmeted motorcyclists had brain injuries compared with nearly a fourth of the helmeted patients. Severe brain injuries were three times as high in non-helmeted patients as in helmeted patients (30% versus 9.3%). The study also shows that deaths from causes other than brain injury was 3.8% in both helmeted and non-helmeted patients.

Gabella et al. (Gabella, Reiner et al. 1995) report on the relationship between helmet use and head injuries among motorcycle crash victims in El Paso County, Colorado, from 1989 to 1990. They report head injuries for 7.6% of motorcycle riders with helmets versus 25.4% of head injuries for motorcycle riders without helmets.

May (May and Morabito 1989) reviewed 225 victims of motorcycle crashes during a 24-month period from 1987 to 1988. The source of the data was the Bay Area Trauma Registry which show that 1 of 60 (1.7%) patients who used helmets died while 7 out of 153 (4.6%) patients who did not use helmets died.

The study by Wagle (Wagle, Perkins et al. 1993) includes 81 motorcyclists involved in crashes and flown to the trauma center of Hartford Hospital, Connecticut. They report that one out of the 23 helmeted motorcyclists died (4.3%), while 9 of the 58 (15.5%) non-helmeted riders died.

Heilman et al. (Heilman, Weisbuch et al. 1982) study motorcycle-related trauma and helmet usage in North Dakota. The study which includes four years of data from 1977 to 1980 concludes that 2.5% of motorcycle riders without helmets in crashes died while 0.8% of motorcycle riders with helmets in crashes died.

Studies Comparing of Death Rates by Helmet Laws

Sosin (Sosin, Sacks et al. 1990) assess fatality data from 1979 to 1986 in order to determine the number of motorcycle fatalities resulting from head injuries in states with and without helmet usage laws. The study used complete death certificate data as well as information from the Fatal Analysis Reporting System (FARS) to compare the type of injury and motor vehicle to the population, demographic and motorcycle registration data during the seven year period. When compared to motorcycle registration, the head-injury involved fatality rate was 3.4 per 10,000 registrants. The fatalities per registrant rate was

higher in states with partial laws (such as age requirements, etc.), but was highest in states with no helmet usage laws. The authors acknowledge that using motorcycle registrations for normalizing fatality data does not account for motorcycle usage. Also, other factors may affect the rate of fatalities from state to state. States with a large and very active population of motorcycle riders also tend to have no mandatory motorcycle helmet laws because of stronger motorcycle lobbies. However, the study also shows that the percentage of deaths relative to the number of motorcycle crashes is 0.3 percentage points higher in states without a mandatory helmet law (2.2%) compared to states with a mandatory helmet law (1.9%).

Auman et al. (Auman, Kufera et al. 2002) studied the impact of Maryland's all-rider motorcycle helmet law enacted in October, 1992. The authors compared 33 seasonal months preceding the law (January 1990 to September 1992) with 33 seasonable comparable months (January 1993 to September 1995) following the enactment of the law (January, 1993 to September, 1995). The motorcycle fatality rates (per 100,000 registered motorcycles) dropped from 10.3 pre-law to 4.5 post law. However, the rate of fatalities per 100,000 registered motorcycles may not be a reliable measure because it does not account for changes in usage such as vehicle miles traveled and the subsequent number of crashes.

A similar study of a mandatory helmet usage law was conducted in Taiwan where motorcycles are most commonly used. The study focused on the resulting head injuries associated with the law change (Chiu, Kuo et al. 2000). A mandatory helmet usage law was enacted on June 1, 1997. In order to study the law's effect, head injuries were compared for the year preceding and the year after the law's passage. The authors, however, only collected data which represented 80% of Taiwan's motorcycle population. Information from more rural areas with smaller hospitals was excluded from the study. Also, patients who were considered dead on arrival or were not hospitalized were not counted. The Taiwan Department of Transportation assigned officers in 23 cities and towns to observe the number of helmeted motorcycle drivers per 200 motorcyclists. The Glasgow Coma Scale score was used to measure the severity of the head injuries. A total of 8,795 cases of "hospitalized patients with motorcycle-related head injuries" were analyzed in the study. Before the helmet law, it was reported that only 21% of

motorcyclists used helmets, while 95.95% used helmets after the law was in place. Motorcycle-related head injuries decreased from 5,260 in the year before the law was passed to 3,535 in the year following the passage of the law. The number of hospitalized patients with motorcycle-related head injuries decreased from 211 to 141, and skull fractures were reduced by 34.3% from 839 to 551. While this study confirmed the decrease in injuries and injury severity due to the mandatory motorcycle helmet law, it neglected to account for victims who were dead at the scene or dead on arrival which could have been caused by head injuries.

Kraus et al. (Kraus, Peek et al. 1994; Kraus, Peek et al. 1995; Kraus, Peek et al. 1995) studied the effect of the 1992 California motorcycle helmet use laws. They report a 37.5% decrease in fatalities from 523 fatalities in 1991 to 327 fatalities in 1992. However, since the number of fatalities in motorcycle crashes had been on a downward trend in California since 1984, it is not clear how much of the decline from 1991 to 1992 would have occurred without the new law. The authors estimate that between 92 and 122 fewer motorcycle fatalities occurred in 1992 than would have been expected without the law. This prediction is based on a regression for the fatality rate per 100,000 motorcycles. The percentage of fatalities based on the total number of injuries declined from 17. 6% in 1991 to 15.7% in 1992. However, the difference of 1.9% is not statistical significant. Unfortunately, no information on the number of motorcycle crashes is provided to normalize the fatality data.

Chenier and Evans (Chenier and Evans 1987) studied the effect of the repeal of mandatory helmet laws by comparing motorcycle fatalities in states which repealed the mandatory helmet laws and states which did not repeal the law. They found that states which repealed the law had a 25% increase in fatalities above the number of fatalities in states which did not repeal the law. Since the authors used raw fatality data, they acknowledge that part of the increase may have been caused by an increase in motorcycle use in states where the laws were repealed. The authors state that “it seems unlikely that such an effect would be zero, but also unlikely that it could be as large as the 25% found here.”

Bledsoe [(Bledsoe, Shexnayder et al. 2002), (Bledsoe 2004), (Bledsoe and Li 2005)] examined the effects of the repeal of Arkansas’s mandatory helmet law in 1997 on

motorcycle registrations, crash and fatality risks, and alcohol involvement in motorcycle crashes by comparing data collected three years before and three years after the repeal. Their study found that motorcycle fatalities not wearing a helmet increased from 37% to 76% after the repeal and the percentage of deaths in motorcycle crashes increased from 4.0% in 1993 -1996 to 4.2% in 1998-2001.

Nurchi (Nurchi, Golino et al. 1987) report on the rate of motorcycle road crashes before and after the compulsory protective helmet law in Italy. The number of in-patients with head injuries decreased form 79 to 37 and the fatalities also decreased from 9 to 1 from 1985 to 1986. Thus, the percentage of deaths decreased from 11.4% to 2.7%.

Muelleman (Muelleman, Mlinek et al. 1992) use crash data from two urban counties representing 40% of Nebraska's population to study the effect of the reenactment of the comprehensive helmet use law in Nebraska, January 1st, 1989. The authors report a "26% decrease in the reported rate of motorcycle crashes in Nebraska compared with five other midwestern states." There were sharp declines in reported injuries and deaths as well. However, since the number of motorcycle crashes declined in all Midwestern states, it is impossible to assess exactly how much of the decline in Nebraska was do to the reenactment of the helmet law. The percentage of killed motorcycle riders relative to all injuries declined a non-significant 0.5 percentage points from 1988 (2.9) to 1989 (2.4). The authors also report that the percentage of serious head injuries was significantly lower among the helmeted motorcyclists (5%) than among un-helmeted cyclists (14%) for the two years 1998 and 1989.

McSwain (McSwain and Lummis 1980) study the effects of the change in the Kansas mandatory helmet law in July 1976. The number of motorcyclists killed increased from 38 in 1975, the year before the law was changed, to 55 in 1977, the year after the law was changed, while the number of crashes increased from 1876 to 2261 during the same period. The percentage of deaths based on all motorcycle crashes increased from 2.0% in 1975 to 2.4% in 1977.

Studies Questioning the Effectiveness of Helmet Laws

While most of the published studies reported that helmets reduce the risk of fatal injuries, a few studies report not finding a significant relationship between helmet use and

risk of fatal injury. Goldstein (Goldstein 1986) develop a causal model for the probability of fatality, the severity of neck injury and the severity of head injury. He concludes that "(1) motorcycle helmets have no statistically significant effect on the probability of fatality, and that (2) past a critical impact speed helmets increase the severity of neck injuries." It is also shown that helmets reduce the severity of head injuries. His conclusions are based on the in-depth analysis of 644 motorcycle crashes in Los Angeles. The probit model used by the author shows no statistically significant effect of helmet use on the probability of death. However, it should be noted that the author does not prove that helmets have no effect on the probability of death in motorcycle crashes. In fact, the estimate for motorcycle helmet use is not zero. The author only fails to find a statistically significant effect in his limited study of 644 crashes. The small sample size is likely responsible for not finding the effect to be significant. Motorcycle fatalities make up a relatively small percentage (about 5%) of all motorcycle crashes. Thus, although the study does not report the number of fatalities in the sample, the number of fatalities may have been below 40, and it is unclear how many of these were wearing a helmet. Statistical models for estimating small proportions are known to have low power in detecting significant effects. The study also failed to provide information about the selection of the original 900 crashes and how the sample was reduced to 644 cases. It is important in a statistical study that a random sample be used if the population data are not available. Other studies, see [(Orsay, Muelleman et al. 1994), (Bachulis, Sangster et al. 1988)], show that spinal injuries were not significantly associated with helmet use while head injuries were markedly reduced by helmet use.

Fleming (Fleming and Becker 1992) study the impact of the Texas Motorcycle Helmet Law on total and head-related fatalities. Texas implemented a mandatory total motorcycle helmet law for all operators and passengers, effective September 1, 1989. The study uses time-series intervention methodology on the monthly numbers of fatalities in motorcycle crashes from September, 1984 to August, 1990. The authors find a 12.6% decline in fatalities in the twelve months after the law was passed. However, due to the large variation in the data, the estimate is not statistically different from zero at a 95% confidence level.

Stolzenberg et al. (Stolzenberg 2003) analyzed the effect of the repeal of Florida's mandatory motorcycle helmet-use law on serious injury and fatality rates. The authors compared motorcycle injuries and fatalities per 100,000 motorcycle registrations for the 174 months (January 1986 to June 2000) preceding the repeal of the helmet-use law with the 18 months (July 2000 to December 2001) following the repeal of the law. Their multivariate transfer function analysis approach does not show any significant increase in the injury and fatality rate. The authors state that the "absence of any effect is rather surprising" and they offer some explanations. However, it should be noted that not finding a significant effect does not imply that there is no effect. In fact, there could be several reasons for not finding a significant effect. The noise variation, for example, could be too large to detect the effect, or the methodology used could be responsible, and, of course, there could be no effect. It is important to carefully examine all of these issues before concluding that there was no effect. For instance, Muller (Muller 2004) used essentially the same Florida crash data from 1994 to 2001 to conduct an interrupted time series analysis. His study concludes that the repeal of the motorcycle helmet-use law resulted in a 48.6% increase in motorcyclist deaths. Even after adjustments for concurrent increases in motorcycle registrations and/or in miles traveled were used, the increase was 21.3% and 38.2%, respectively. Hotz et al. (Hotz, Cohn et al. 2002) also studied the effect of the repealed motorcycle Helmet Law in Florida. Their study used data from the University of Miami/Jackson Memorial Medical Center. They reported that the number of brain injuries of motorcycle riders in this hospital almost doubled (from 18 to 35) after the repeal of the helmet law and the number of fatalities quadrupled from 2 to 8 for comparable time periods. Although the increase may have been partly caused by an increase in motorcycle crashes, the study also contradicts the findings of Stolzenberg et al.. One reason that the study of Stolzenberg et al. may have failed to detect a significant effect is that the variation of the crash rates between months was rather large and ranged from a low of 4 to a high of 12. Also, the measure used, namely, the fatality rate and the injury rate based on 100,000 motorcycle registrations, may be responsible for not detecting any effect. If the number of registrations increases and the number of fatalities remain constant, then the rate would actually decrease. However, the number of registered motorcycles is not the population at risk. In fact, some registered vehicles may

not be used at all. Another issue which confounds the findings of Stolzenberg et al. is the number of motorcyclists actually wearing helmets. The percentage of motorcyclists not wearing helmets may have not changed dramatically after the law was repealed. In summary, because no statistical significance can be associated with the Stolzenberg's findings, no reliable conclusions can be drawn from the study.

3. Louisiana Crash Data

The data for this study were taken from the Louisiana crash records file maintained at Louisiana State University. Crash records are filled out either on paper forms or electronically by the investigating officer and checked by his/her supervisor. The officer fills out the vehicle type. A closer look at the data indicated several problems. First, there were two vehicle types which are sometimes confused by the officer: motorcycles and off-road vehicles. For this reason, the VIN number was compared with the classification of the manufacturer. All four-wheelers and three-wheelers off-road vehicles were excluded in this study, although there are some three-wheel motorcycles designed for driving on the road which were included. Secondly, also excluded from this study were vehicles which were misclassified by the officer (judged by the VIN number) and vehicles which were coded as motorcycles but did not have a valid VIN number nor a description of the make of the motorcycle.

The injury code was taken from the crash report:

A-FATAL,

B-INCAPACITATING/SEVERE,

C-NON-INCAPACITATING/MODERATE,

D-POSSIBLE/COMPLAINT, E- NO INJURY.

When studying the effectiveness of motorcycle-helmet laws, the effectiveness of helmets and the effectiveness of the laws need to be separated. Judging the effectiveness of helmet-use laws not only involves the actual number of injuries and the severity of injuries in a crash, but also compliance to the law. Although many studies focus on states which have changed their law [(Stolzenberg 2003), (Bledsoe, Shexnayder et al. 2002), (Auman, Kufera et al. 2002)], they do not account for compliance to the law.

The effectiveness of helmets on injury severity in a crash can be either measured by laboratory experimentation or by the number of injuries and its severity in a crash. While in a laboratory experiment such as testing with dummies, extraneous factors can be accounted for in some form by either keeping them constant or controlling the effect of the extraneous factors; in an observational study such as crash analyses, many extraneous factors exist which are difficult to measure and impossible to control. For instance, the actual number of motorcycles registered and the vehicle miles traveled influence the number of crashes and subsequent injuries. Thus, most studies use rates based on the number of registered motorcycles or vehicle miles traveled (VMT) to measure the effectiveness of helmet laws or helmet use. However, the number of registered motorcycles and the VMT may not be accurate measures of the population under risk. For instance, during the last ten years, motorcycles gained popularity among baby boomers as a leisure sport. Usage among this group may be very different from usage among groups driving to and from work. Hence, the risk of serious injuries may not be proportional to the number of registrations. VMT is more closely related to risk but reliable estimates are not available. Also, there are many other factors which affect the number of crashes and may change over time, independent of VMT. Over the past ten years, the average age of drivers has increased due to the aforementioned popularity of motorcycles among baby boomers; motorcycles have become more powerful; average speeds have increased; the percentage of motorcycle riders wearing helmets has changed. It is difficult if not impossible to account for all these changes in an observational study. Thus, it is very important to use a measure which is least affected by these extraneous factors. Most of these factors are related to vehicle usage but are unrelated to wearing or not wearing a helmet. Motorcycle helmets only protect against injuries in crashes. Hence, adjusting fatality data by VMT or the number of registered vehicles does not properly take into account the population at risk. Only the motorcycle riders in a crash are at risk of being killed or injured and this risk is moderated by wearing a helmet. Wearing or not wearing a motorcycle helmet should not affect the probability of being in a crash. Although it may be argued that the number of motorcycle riders in a crash is related to the number of registrations of motorcycles and VMT, it is not clear at all how close this relationship is and whether it remains constant over time. For instance, a doubling of

VMT does not necessarily imply a doubling of the number of motorcycle crashes. Therefore the most suitable measure is the percentage of drivers or occupants of a motorcycle injured or killed in a crash. This measure is very little, if at all, affected by changes in the driving population or the vehicle miles driven. Also, since this percentage is unrelated to the existence or non existence of mandatory helmet laws, crash information from states with and without mandatory helmet laws may be used.

Effect of Helmet Use

While there are possibly several factors contributing to the increase in fatality rates, helmet use is of particular interest because of the change in the law in Louisiana. Unfortunately, in many cases, helmet use is unknown. Table 1 shows the percentage of helmet use by injury severity. For crashes with no injuries, helmet use was largely not reported. The last column of Table 1 reports the estimated percentage of helmet use. This percentage underestimates the true helmet use percentage considerably. For instance, in 2005 the estimated percentage for helmet use based on the crash reports was 84%, while the observational surveys showed that 99% of motorcycle riders were using a helmet in 2005.

Table 1: Percent Helmet Use (1999 to 2005)

	Helmet Use			
	No	Yes	Unknown	Estimated Helmet Use
FATAL	53%	41%	6%	44%
INCAPACITATING/SEVERE	46%	45%	9%	49%
NON-INCAPACITATING/MODERATE	38%	54%	8%	58%
POSSIBLE/COMPLAINT	33%	55%	11%	62%
NO INJURY	14%	23%	62%	62%
Total	32%	45%	23%	59%

The analysis uses only cases where helmet use was known, thus excluding crashes with unknown helmet use. The effect of excluding unknown cases is that the benefit of helmets in reducing crashes is underestimated. Table 2 presents the percentage of drivers and occupants killed in all motorcycle crashes by helmet-usage from 1999 to 2005 including only known helmet use. The first three columns give the percentages based on

all crashes, while the last three columns give the percentages based on only injury crashes. Although the analysis based on injury crashes is more reliable because of a higher percentage of known cases, the conclusions do not differ much whether all crashes or only injury crashes are used.

Table 2: Percent Death by Helmet Use (1999 to 2005)

	Based on All Crashes			Based on Injury Crashes Only		
	Non-helmeted	Helmeted	Diff	Non-helmeted	Helmeted	Diff
1999	6.5%	4.0%	2.5%	7.1%	4.3%	2.8%
2000	5.5%	4.1%	1.3%	5.9%	4.6%	1.3%
2001	6.0%	3.3%	2.8%	6.6%	3.6%	3.1%
2002	6.3%	2.7%	3.6%	7.3%	3.1%	4.3%
2003	6.9%	3.5%	3.4%	7.5%	3.9%	3.6%
2004	5.9%	3.4%	2.5%	6.7%	3.9%	2.7%
2005	6.6%	3.6%	3.0%	8.8%	4.5%	4.3%
Average	6.2%	3.5%	2.7%	7.0%	4.0%	2.9%

Between 1999 and 2005, on the average, 3.5% of motorcycle drivers wearing helmets were killed in crashes, while 6.2% of motorcycle riders without helmets in crashes were killed. The 2.7 percentage point difference amounts to an increase in risk of fatality of 77.3% when not wearing a helmet. If only injury crashes were used, the percentages would be 7% for occupants with helmets versus 4% for occupants without helmets. The percentage point differences were significant at the 0.001% level which clearly indicates that not wearing a helmet increases the risk of motorcycle drivers being killed in a crash.

Table 3 shows the fatalities and injuries of drivers only for crashes with known helmet use; again, this excludes all unknown cases in the calculations. It is evident from Table 3 that, from 1999 to 2005, on the average, the fatality rate tends to be 3.0 percentage points higher for motorcycle drivers not wearing a helmet than for motorcycle drivers wearing a helmet, and severe injuries tend to be on the average 3.1 percentage points higher for motorcycle drivers not wearing a helmet than for motorcycle drivers wearing a helmet. This amounts to an increase in risk of fatality of 83% and an increase in risk of being severely injured of 43%. These differences are significant at the 0.001%

level. The last three columns of Table 3 show the same estimates based on injury crashes only. The estimates of the difference tend to be higher because of fewer unknown helmet use cases. It should be pointed out that the 2005 data had the lowest percentage of unknown helmet use and therefore the 2005 estimates are the most reliable.

Table 3: Fatalities and Injuries by Helmet Usage and Injury Severity

	Based on All Crashes			Based on Injury Crashes Only		
Severity	Non-helmeted	Helmeted	Difference	No Helmet Used	Helmet used	Difference
FATAL	6.6%	3.6%	3.0%	7.4%	4.2%	3.2%
INCAPACITATING/SEVERE	10.4%	7.2%	3.1%	11.6%	8.3%	3.3%
NON-INCAPACITATING/MODERATE	40.0%	39.0%	1.0%	44.8%	44.9%	-0.1%
POSSIBLE/COMPLAINT	32.2%	37.0%	-4.8%	36.1%	42.6%	-6.5%
NO INJURY	10.8%	13.1%	-2.3%			

The analysis of motorcycle crashes clearly shows beyond reasonable doubt that helmets reduce the percentage of fatalities and serious injuries in motorcycle crashes and fatalities. We can safely conclude, therefore, that the change in the mandatory helmet law in 2004 had an affect on the percentage of fatalities. Thus, the observed percentage of motorcycle fatalities should have declined after 2004. Table 4 shows the number of motorcycle rider fatalities from 1999 to 2005.

Table 4: Motorcycle Crashes from 1999 to 2005

Year	# of Fatalities	# of Motorcycles in Crashes	Fatalities per 100 Crashes
1999	42	1138	3.7%
2000	57	1381	4.1%
2001	62	1414	4.4%
2002	65	1563	4.2%
2003	80	1791	4.5%
2004	79	1917	4.1%
2005	74	1843	4.0%

The number of motorcycles involved in crashes increased by 57% from 1999 to 2003; however, the number of motorcycle rider fatalities increased by 90% during the same time period. The fatality rate (fatalities per 100 crashes) also increased from 3.7%

in 1999 to 4.5% in 2003. The data show that the fatality rate declined since 2004 when the mandatory helmet law was reinstated, to 4.0% in 2005.

Other Factors

There are other possible contributing factors which could have played a role in the increase in fatality percentages. One of the predominant factors is alcohol use. Table 5 shows the percentage of motorcycle riders in crashes killed by helmet use and alcohol involvement. The probability of motorcycle riders without helmets dying increases from 6.6% to 19.7% when alcohol is involved and the difference between the fatality probability when wearing and not wearing a helmet increases from 3 percentage points to 4.8 percentage points when alcohol is involved. When no alcohol is involved, the difference between the probability of being killed in a crash when wearing and not wearing a helmet is only 1 percentage point. Although this percentage difference seems small, it still amounts to a 37% increase in the risk of being killed.

Table 5: Fatalities and Injuries by Helmet Usage and Alcohol Involvement

Severity	No Helmet Used	Helmet used	Difference
Alcohol Involved			
FATAL	19.7%	14.9%	4.8%
INCAPACITATING/SEVERE	18.9%	12.8%	6.1%
NON-INCAPACITATING/MODERATE	34.9%	41.9%	-6.9%
POSSIBLE/COMPLAINT	22.1%	21.9%	0.3%
No Alcohol Involved			
FATAL	3.5%	2.6%	1.0%
INCAPACITATING/SEVERE	8.7%	6.8%	1.9%
NON-INCAPACITATING/MODERATE	41.1%	38.7%	2.5%
POSSIBLE/COMPLAINT	34.3%	38.6%	-4.3%

There are some other observations based on the Louisiana Crash Data. For example, between 1999 and 2005, 42% of all fatal motorcycle crashes did not involve other vehicles and 73% of killed motorcycle drivers were at fault, showing that in a large percentage of fatal motorcycle crashes the responsibility for being killed rests with the motorcycle driver.

Endorsements may not be a factor in reducing fatalities. While 40% of motorcycle riders killed had endorsements, 31% of those who were injured had endorsements. The data also showed that 5% of motorcycle drivers in crashes with a motorcycle endorsement were killed, while 3% of drivers in crashes without a motorcycle endorsement were killed.

Harley Davidson drivers had a higher percentage (60%) of alcohol-related fatalities than drivers of other motorcycles (38%). The percentages are 14% and 9%, respectively, for all motorcycle crashes. This confirms the findings of Gabella (Gabella, Reiner et al. 1995) who reported a higher rate of alcohol involvement of Harley Davidson motorcycles in crashes with head injuries.

4. Conclusions

Despite the overwhelming research suggesting that motorcycle helmets save lives, there are many states which don't have a mandatory helmet law. Also, many motorcyclists consider requiring motorcyclists to wear helmets an infringement on individual freedom and some criticize the published research. For example, the *American Motorcyclist* published a report disputing findings by the *American Medical Association* and the Center for Disease Control (CDC) in Atlanta in support of mandatory helmet laws (1991). The American Motorcyclist article states, "They've specifically used bad data to come up with meaningless results in a study that purports to prove that all states should adopt mandatory helmet laws for motorcyclists." The article argues that the best way to compare motorcycle crash data is by using motorcycle miles traveled which the CDC Control admitted to not having available for their research. The article also states that the CDC noted that "head injury-related" fatalities decreased, but did not compare the change in total fatalities which should be important to motorcyclists as well.

There are three objectives in the present study: (1) to determine a proper methodology, i.e. normalization of fatality data, (2) to provide evidence regarding the hypothesis that helmets reduce the occurrence of severe and fatal injuries, (3) to determine the effectiveness of mandatory helmet laws.

This article discusses the proper methodology and the normalization of the number of fatalities and argued that using vehicle miles traveled or motorcycle

registrations is inappropriate. The measure of effectiveness of motorcycle helmets is the percentage of motorcycle riders surviving a crash or not being severely injured. For convenience we use its complement, the percentage of occupants being killed or injured. Vehicle miles traveled or registrations may be used to normalize crash data, but they are unrelated to whether or not a helmet saves lives in the case of a crash. Using the VMT is similar to stating the probability of a person being killed by a shark based on the population of the United States. Only those who are swimming in the ocean are at risk of being bitten by a shark and only those motorcyclists who are in crash are at risk of being killed or having a severe injury.

Louisiana crash data show that the risk of being killed in a motorcycle crash almost doubles (+82%) when the motorcyclist does not wear a helmet compared to motorcyclists who do wear a helmet. Furthermore, the risk of severe injury when not wearing a helmet increases by 43%. These results are significant at the 0.001% level. Thus, there is ample evidence that motorcycle helmets reduce fatal and severe injuries in motorcycle crashes.

We also showed that further reductions in motorcycle fatality percentages may be achieved by taking measures to reduce the number of drivers driving under the influence of alcohol. The data indicate that motorcycle riders driving under the influence of alcohol and not wearing a helmet had the highest fatality percentage of 19.7%. This means about one in five riders who crash will die. Alcohol was also cited as a major factor in non-helmet use and involvement in fatal motorcycle crashes by Bledsoe (Bledsoe and Li 2005).

Other findings suggest that enforcing motorcycle endorsements may not reduce the fatality percentage in crashes. However, the data do not provide any evidence regarding the effectiveness of endorsements in reducing motorcycle crashes.

This article also provides evidence that mandatory helmet laws are effective in reducing fatalities among motorcycle riders. The percentage of fatalities in motorcycle crashes steadily increased from 3.7% in 1999 when the mandatory helmet law was repealed to 4.5% in 2003; this reflects a decline in motorcyclists wearing a helmet from 54% in 1999 to 36 % in 2003. In 2004 the mandatory helmet law was reinstated and the

fatality percentage declined to 4.0% in 2005 when the percentage of riders wearing helmets increased to an estimated 81%.

How do the conclusions in this article compare to other articles published in the literature? Table 6 compares the fatality rates or injury rates of published articles. Only a few articles report the number of all motorcycle crashes and riders involved in crashes. The rates vary substantially depending on the denominator of the rate. However, all studies reporting total injuries or total number of riders involved in crashes show that the odds ratio of being killed not wearing a helmet is on the average larger than two and the odds ratio for incurring a serious head injury is larger than three.

Table 6: Death and Serious Head Injury Rates for Helmeted Versus Non-Helmeted Motorcycle Riders

Rates as percent of all (*)/injured (**)/fatal (***) riders

	Fatalities		**Fatal**	**Serious Head Injuries***		**Serious Head Injuries**
Author	**Helmeted**	**Non-Helmeted**	**Odds Ratio**	**Helmeted**	**Non-Helmeted**	**Odds Ratio**
Watson et al. 1980 ***			1.4			
Heilman et al. 1982*	0.8%	2.5%	3.1			
Gabella et al. 1995 *				7.6%	25.4%	3.3
Bachulis et al. 1988**	5.3%	9.8%	1.8	9.3%	30.0%	3.2
May et al. 1989**	1.7%	4.6%	2.7			
Wagle et al. 1993**	4.3%	15.5%	3.6			
Muelleman et al. 1992**				5.0%	14.0%	
Schneider 2007 *	3.5%	6.2%	1.8			
Average	**3.1%**	**7.7%**	**2.4**	**7%**	**23%**	**3.3**

Table 7 gives a summary of the articles reporting death rates based on riders involved in crashes for states which either instated or repealed the mandatory helmet law. The table also includes a study which compares several states with different helmet laws.

Table 7: Death Rates by Helmet Use Law

Authors	State	Helmet Law	No Helmet Law	Odds Ratio	Denominator
Kraus, Peek et al. 1995	California	15.7%	17.6%	1.12	Hospitalized only
Muelleman, Mlinek et al. 1992	Nebraska	1.1%	1.4%	1.26	All Crashes
McSwain and Lummis 1980	Kansas	2.0%	2.4%	1.20	All Crashes
Bledsoe et al. 2005	Arkansas	4.0%	4.2%	1.05	All Crashes
Sosin, Sacks et al. 1990	USA	1.9%	2.2%	1.16	All Crashes
Schneider 2007	Louisiana	4.0%	4.5%	1.13	All Crashes
Average				**1.15**	

All articles reporting crash rates based on the total number of crashes report odds ratios larger than one. The average odds ratio reported is 1.15 which is lower than the odds ratios depicted in Table 6. The reason for this difference in the effectiveness of helmets versus the effectiveness of mandatory helmet laws is the fact that not all motorcycle riders will use helmets after the law is changed. The percentages shown in Table 7 include a number of motorcycle riders which don't wear helmets. However, the data show that there is considerable published evidence that mandatory motorcycle helmet laws result in a significant reduction in the percentage of motorcycle riders killed in crashes.

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