TRAUMATIC BRAIN INJURY ASSOCIATED WITH MOTORCYCLE CRASHES IN WISCONSIN, 1991-1997

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ABSTRACT
We evaluated the impact of a variety of motorcycle crash related factors, including crash type, speed limit, highway type, demographics, alcohol involvement and helmet use, on the likelihood of being hospitalized for traumatic brain injury (TBI) and subsequent injury severity and hospital resource utilization. Helmet use was found to have a strong protective effect on the likelihood of TBI across all other factors. Alcohol involvement in the crash was found to increase the probability of TBI, as were higher speed limits and crash configurations increasing the force of impact in a motorcycle crash. However, no explanatory variable had a statistically significant effect on hospital charge or days, or on injury severity once hospitalized.

Injuries associated with motorcycle crashes are a major cause of morbidity and mortality in the United States (1). The injury severity and outcomes of a motorcycle crash are more severe than for crashes involving passenger vehicles (2). In 1996-1997 there were 164.1 hospitalizations per 1,000 motorcycle crash drivers and riders as opposed to only 10.6 hospitalizations per 1,000 passenger vehicle occupants in Wisconsin. Similarly, there were 26.0 fatalities per 1,000 Motorcycle crash drivers and riders as opposed to only 1.9 fatalities per 1,000 passenger vehicle occupants.

One of the major sources of injuries associated with motorcycle crashes are head injuries (3,4,5,6,7). While studies of motorcycle crash outcomes have consistently shown that helmet use is strongly associated with traumatic brain injuries (TBI) (3,4,5,6,8,9,10,11), few have evaluated the impact of helmet use in the context of crash characteristics, demographic factors and alcohol use.

In our study we perform a retrospective cohort study which links together crash and demographic factors with information on helmet use and alcohol involvement to evaluate several crash outcomes:

- Hospitalization with associated traumatic brain injury (and subsequently)
  - ⇒ Average abbreviated injury scores (12)
  - ⇒ Injury severity scores (12)
  - ⇒ Hospital charges
  - ⇒ Hospital length of stay

We hypothesize that the lack of helmet use will have a strong impact on the likelihood of TBI, and may effect the other outcomes negatively as well. We also hypothesize that alcohol involvement, older age and crash characteristics which increase the force of impact in a crash (e.g. higher speed limits as a proxy for speed, head on collisions with another vehicle) will positively effect our outcomes.

METHODS

Data Sources – The data used in this analysis is from the Wisconsin Crash Outcomes and Data Evaluation System (CODES) database. The Wisconsin CODES project is funded through grants from NHTSA and the Bureau of Traffic Safety within the Wisconsin Department of Transportation. The CODES data is comprised of two sets of records.. The first is the Wisconsin motor vehicle crash records data. The 1991-1997 crash records data was obtained through the Department of Transportation. This crash data contains information on all reportable crashes (with at least one injury or fatality, or at least $1000 in property damage (1994-1997) , $500 for 1991-1993). The data are collected by police officers at the crash scene, and include detailed information on the time, location and characteristics of the crash, as well as on the vehicle(s) and occupant(s) involved. The 1991-1997 hospital discharge data is obtained from the Office of Health Care Information within the Wisconsin Department of Health and Family Services. The Department mandates that all Wisconsin licensed hospital reports all inpatient discharges. Additionally, the same data is collected from Michigan, Iowa and Illinois. This data combines detailed information on patient demographics, up to nine ICD-9 and five procedure codes, an external cause of injury code (E-Code), charges and length of stay.

Probabilistic Data Merging – The CODES analysis database was created by using a technique called "probabilistic linkage" (13). By utilizing common information in both data sets, probabilistic linkage iteratively estimates a set of weights used to determine the probability that specific records apply to the same person. The information used to link Wisconsin's CODES data included sex, age, date of birth, zip code of residence, county of crash and hospitalization, E-code and dates of hospitalization and of the crash.

Definitions -- Motorcycle crashes refer to both drivers and passengers of motorcycles. Motor scooters and mopeds were excluded from the analysis. Traumatic brain injury includes hospitalizations with ICD-9 codes indicating either skull fracture or brain injury. Concussions were not included in our analysis unless accompanied by skull fracture or brain injury since it was felt that a large percentage of such cases do not result in hospitalizations. Hospitalized persons were those whose crash record was probabilistically linked to a hospital discharge record. Study variables used in the analysis are described in Figure 1 (at the end of the discussion section). Table 1 contains information on the number of cases and percentages for the study variables.

Analysis – For the TBI outcome, relative risk ratios and chi square statistics were used to evaluate the impact of helmet use within categories of the study variables, and to evaluate categories of the study variables themselves to a comparison group. Logistic regression was used to estimate the effect of all study variables simultaneously. For the other four outcomes (average AIS score, ISS score, charges and length of stay) T-Tests and OLS regression was used.

Software – Automatch 4.2 (Matchware Technologies, Inc., Boston, MA) was used to perform probabilistic linkage. AIS and ISS scores were generated using ICDMAP-90 software (Tri-Analyticss, Inc., Boston, MA). SAS software (SAS Institute, Inc., Cary, NC) was used for all statistical analysis.

RESULTS

In Wisconsin, from 1991-1997, there were a total of 18,394 drivers and passengers of motorcycles involved in crashes (from Table 1). Males made up the overwhelming percentage of victims: 83.7%, and a majority were between the ages of 19 and 34. Crashes were evenly divided between urban and rural locations, with a majority occurring on a local road and an additional 31.6% occurring on state highways. Alcohol was indicated as being involved for 14.2% of crash victims. Helmet use was reported only 28.9% of the time, with missing helmet information in 8.8% of all cases. Of those involved in a motorcycle crash, 4.7% were hospitalized and had a diagnosis of TBI. For those with TBI, the average hospital charges were almost $29,000, the length of stay was just over 10.5 days, the average AIS was 3.52 and the average ISS was 18.47.

Table 2 provides a bivariate analysis of the relative risk of suffering a TBI if not wearing a helmet by comparison to those wearing a helmet, for categories of the other study variables. For almost every category of the study variables, not wearing a helmet leads to significantly higher risk of TBI by comparison to those wearing a helmet. Overall, the risk ratio is 3.65 for all cases. The relative risk ranges from a low of 2.56 (for those with alcohol related to their crash), up to a risk ratio of 6.60 for a motorcycle crash involving only the motorcycle hitting a fixed object. Only three categories (age 65+, 2 vehicle collision involving a side swipe and crashes on a federal interstate) do not show a significant difference between those with and without helmets.

Table 3 provides the relative risk ratios for the likelihood of TBI for categories within the study variables as opposed to a comparison group. The comparison categories are indicated in the table. In general, the relative risk increases as speed increases, for most categories of crash configuration by comparison to a rear end collision, for reported alcohol involvement in the crash and for not wearing a helmet. At this level of comparison, there is no significant difference in the risk of TBI for someone on a local road as opposed to county roads, state highways or federal interstates. Most notably, none of the demographic variables show any statistically significant difference with the comparison group.

Table 4 shows the results from two different logistic regressions run with a complete model including all of the study variables except the demographic variables. The demographic variables were excluded from the model because none of the categories was statistically significant either in Table 3, nor in a full logistic regression model which included them. The difference between the two models lies in the way helmet use and alcohol involvement were modeled. In the first model, simply the main effects of helmet use and alcohol were included. In the second model, specific joint categories of helmet use and alcohol involvement in the crash were included.

With all variables in the model, speed limit shows a statistically significant monotonic increase in the odds ratio for TBI for all categories of speed limit. Two of the three road type categories have significant differences from local roads, with both county and federal interstate roads being associated with a lower likelihood of TBI. Rural crashes have a significant higher ratio of 1.31 for TBI. Finally, crash configurations with greater impact (head on) or involving unyielding objects have a much higher likelihood of leading to TBI by comparison to rear end collisions.

Perhaps the most interesting results are for the helmet and alcohol variables. As expected, both not wearing a helmet and alcohol being a factor in the crash have significant and positive main effects on the likelihood of TBI. Cases with missing helmet information are more like cases not wearing a helmet than like those who were wearing helmets. However, when the helmet and alcohol variables are combined, there appear to be at least limited interaction effects with the alcohol variable. The comparison group for this model are persons wearing helmets, for whom police did not report alcohol being a factor in the crash. Comparing helmeted victims for whom alcohol was reported as being a factor, the net impact of alcohol being involved is an odds ratio of 3.43. But for persons not wearing a helmet, the odds ratio increases from 3.43 (no alcohol) to 9.20 for cases in which alcohol was a factor. For cases with missing helmet information, the numbers are similar, with the odds ratio increasing from 2.42 (no alcohol) to over 10.2.

Table 5 shows the results for the other outcome variables. Estimates of the simple bivariate level impact of helmet use status on the four outcomes shows no significant effect. This is true for both all TBI cases, and for those included only if the maximum injury severity score was for the head or neck body region – cases most likely to show the biggest difference in TBI outcomes. OLS regression estimates (not shown) revealed no statistically significant impacts of any of the study variables on these four outcomes. This was true even after various outlier trim points were utilized.

DISCUSSION

Our results have replicated those of other studies which clearly show helmet use to be protective against serious head injuries in the event of a motorcycle crash. However, unlike some studies (10,16), we do not find a significant effect of helmet use on either injury severity (AIS/ISS) or resource utilzation measures (hospital charges and length of stay). The differences between our results and those of other studies may be a result of case selection. In other analyses, severity and resource utilization were measured for all hospitalized motorcycle crash victims – whereas in our analysis, we only included hospitalized cases with serious head injuries. Also, the use of a limited number of emergency departments for sample selection may have provided biased results in some studies. Two other studies which utilized statewide data and evaluated severity and resources used for head injury patients found the same results as we did (3, 12) – no significant differences between severity and resources used for head injury patients. Using data from a statewide trauma registry, Rutledge and Stutts found a protective effect for helmet use – but found no significant differences for other outcome measures such as hospital days and charges. Similarly, Rowland et.al. analyzed statewide data for Washington and found a significant protective effect for helmets on the likelihood of head injuries, but found no significant differences for most other measures of severity and resource utilization. We conclude that the effect of helmets on head injuries in the event of a motorcycle crash primarily impact the likelihood of hospitalization. Helmeted crash victims do not have serious head injuries in the same proportion as those without helmets, and thus have lower severity and resource utilization overall. But once they are hospitalized

Figure 1.

Helmet Use:	As reported by police officer on scene. Helmeted, not helmeted and unknown/missing.
Alcohol Use:	Combines BAC results with police officer report of whether or not alcohol was a factor in the crash. No alcohol involved is the comparison group.
Sex	Male (Female is the comparison group)
Age	< 19, 19-24, 25-34, 35-44, 45-54, 55-64, 65 years or older. (< 19 years is the comparison group).
Rural/Urban	Rural: Unincorporated areas of less than 5,000 population. Urban: Other. (urban is the comparison group)
Speed Limit	5-25 mph, 26-35 mph, 36-45 mph, 46-55 mph, 56+ mph. (5-25 is the comparison group).
Highway Type	Local road, county road, state highway and federal interstate. (local road is the comparison group)
Crash Type	2 vehicle: Rear End (comparison group), side swipe, head on collision. Motorcycle only: Hit fixed object, hit movable object. Other crash type.
Traumatic Brain Injury:	ICD-9 codes: 800.00 – 800.99, 801.00 – 801.99, 802.00 – 803.99, 804.00 – 804.99, 850.20 -- 850.49, 850.60 – 850.89, 851.00 – 854.99
Abbreviated Severity Score	Derived from ICD-9 codes in the 800 to 999 range. Ranges from 1 (minor injury) to 6 (maximal injury).
Injury Severity Score	Calculated from the AIS score. Ranges from 1 to 75.
Hospital Charges	Reported hospital charges.
Hospital Days	Reported hospital days

Table 1. Number and Percent of Cases for Study Variables

INDEPENDENT VARIABLES		
Total Number	18,394	100.0%
Speed 1-25	6,373	34.6%
Speed 26-35	4,190	22.8%
Speed 36-45	1,670	9.1%
Speed 46-55	5,949	32.3%
Speed 56+	212	1.2%
Rural County	9,256	50.3%
Urban County	9,138	49.7%
Local Road	9,450	51.4%
County Road	2,631	14.3%
State Highway	5,807	31.6%
Federal Interstate	506	2.8%
Male	15,396	83.7%
Female	2,561	13.9%
Missing	437	2.4%
Age < 19	1,756	9.5%
Age 19-24	4,579	24.9%
Age 25-34	5,311	28.9%
Age 35-44	3,712	20.2%
Age 45-54	1,810	9.8%
Age 55-64	467	2.5%
Age 65+	161	0.9%
Missing	598	3.3%
Not Helmeted	5,308	28.9%
Helmeted	11,476	62.4%
Missing	1,610	8.8%
Alcohol not a factor	15,784	85.8%
Alcohol a factor	2,610	14.2%
Rear End Collision	2,105	11.4%
Side Collision	1,359	7.4%
Head On Collision	384	2.1%
Hit Fixed Object	2,635	14.3%
Hit Movable Object	2,117	11.5%
Other Type Accident	9,794	53.2%

OUTCOMES		
Traumatic Brain Injury - No	17,568	100.0%
Traumatic Brain Injury - Yes	826	4.7%
<u>Severity Score</u>		
1: Minor	29	3.5%
2: Moderate	119	14.4%
3: Serious	149	18.0%
4: Severe	287	34.7%
5: Critical	127	15.4%
6: Maximum	1	13.9%
Missing	115	13.9%

	Mean	**St. Dev.**
Hospital Charges	$ 28,806	$ 23,064
Length of Stay	10.58	7.97
Maximum AIS	3.52	1.19
Injury Severity Score	18.47	9.96

Table 2.
Relative Risk Ratios for Traumatic Brain Injury for Helmeted vs non-Helmeted Motorcycle Crash Victims, by Categories of Study Variable, Wisconsin, 1991-1997

	Relative Risk Ratio			Relative Risk Ratio	
Total	3.65	*			
<= 25 mph	3.67	*	**< 19 Yrs**	4.75	*
26-35 mh	4.01	*	**19-24 Yrs**	3.73	*
36-45 mph	5.52	*	**25-34 Yrs**	4.21	*
46-55 mph	3.62	*	**35-44 Yrs**	3.51	*
56+ MPH (1)	NA		**45-54 Yrs**	3.46	*
			55-64 Yrs	3.82	*
Urban	4.06	*	**65+ Yrs**	1.70	
Rural	3.37	*			
			Male	3.58	*
Local Road	3.67	*	**Female**	4.39	*
County Road	3.55	*			
State Highway	3.92	*	**Not Alcohol Related**	3.09	*
Federal Interstate	2.51		**Alcohol Related**	2.56	*
2+ Veh, Rear End	6.06	*			
2+ Veh, Side Swipe	2.39				
2+ Veh , Head On	3.06	*			
1 Veh, Fixed Obj	6.60	*			
1 Veh, Movable Obj	5.14	*			
Other	2.91	*			

* Difference between helmeted and unhelmeted victims is significant at the .05 level.
(1) There were no helmeted TBI cases at 56 mph or higher.

Table 3.
Relative Risk Ratios for Traumatic Brain Injury for Categories of Study Variables vs a Comparison Group, Wisconsin, 1991-1997

	Relative Risk Ratio			Relative Risk Ratio	
<= 25 mph	Comparison Group		**< 19 Years**	Comparison Group	
26-35 mh	1.52	*	**19-24 Years**	1.14	
36-45 mph	1.78	*	**25-34 Years**	1.27	
46-55 mph	2.17	*	**35-44 Years**	1.26	
56+ MPH	1.49		**45-54 Years**	1.26	
			55-64 Years	1.37	
Urban (Rural Comparison)	1.29	*	**65+ Years**	1.65	
Local Road	Comparison Group				
County Road	1.17				
State Highway	1.11		**Male**	1.22	
Federal Interstate	0.83				
			Alcohol Involved	3.41	*
2+ Veh, Rear End	Comparison Group		**Not Wearing Helmet**	3.65	*
2+ Veh, Head On	2.62	*			
2+ Veh Side	1.10				
1 Veh, Fixed Obj	3.53	*			
1 Veh, Movable Obj	1.77	*			
Other	2.46	*			

* Difference between category and comparison group are significant at the .05 level.

Table 4.
Results from Full Model for Likelihood of Traumatic Brain Injury for Motorcycle Crash Victims, Wisconsin, 1991-1997

	Odds Ratio	95% Confidence Interval	Odds Ratio	95% Confidence Interval
No Helmet	3.31 *	(2.62 , 4.18)		
Helmet Information Missing	2.72 *	(1.97 , 3.77)		
Alcohol Involved	2.82 *	(2.41 , 3.29)		
No Helmet, Alcohol Involved			9.20 *	(7.02 , 12.05)
No Helmet, No Alcohol Involved			3.43 *	(2.66 , 4.42)
Helmet, Alcohol Involved			3.18 *	(1.73 , 5.85)
Missing Helmet, Alcohol Involved			10.23 *	(6.41 , 16.32)
Missing Helmet, No Alcohol Involved			2.42 *	(1.64 , 3.57)
26-35 mph	1.65 *	(1.29 , 2.11)		
36-45 mph	2.23 *	(1.01 , 4.92)		
46-55 mph	3.26 *	(2.64 , 4.01)	Same as Previous Model	
56+ mph	3.59 *	(2.84 , 4.54)		
Rural	1.31 *	(1.10 , 1.55)		
County Road	0.76 *	(0.44 , 1.32)		
State Road	0.96	(0.60 , 1.54)		
Federal Interstate	0.46 *	(0.26 , 0.81)		
2+ Vehicles, Side Impact	1.04	(0.74 , 1.46)		
2+ Vehicles, Head On	2.09 *	(2.00 , 2.20)		
1 Vehicle, Fixed Object	2.54 *	(1.81 , 3.56)		
1 Vehicle, Movable Object	0.95 *	(0.90 , 0.99)		
Other Crash Configuration	2.35 *	(1.72 , 3.20)		

* Indicates that the difference between the comparison group and the model variable is significant at the .05 level.

Table 5.
Mean and Standard Deviation for Hospital Charges, Hospital Length of Stay, Maximum AIS Score, and Injury Severity Score, for all Traumatic Brain Injury Cases, and those for which the Maximum AIS Score was for the Head Body Region, by Helmet Use, Wisconsin, 1991-1997

	Hospital Charges	Hospital LOS	Maximum AIS Score	Injury Severity Score
All TBI Cases				
No Helmet	$ 28,294	10.39	3.56	18.94
Number=671	$ (36,036)	(13.70)	(1.16)	(11.77)
Helmet Worn	$ 24,501	9.17	3.44	19.41
Number=70	$ (35,182)	(10.79)	(1.33)	(14.29)
Missing Helmet Information	$ 44,822	14.61	3.66	19.72
Number=85	$ (103,071)	(31.09)	(.93)	(11.03)
Only TBI Cases where Maximum AIS Score is for Head Injury				
No Helmet	$ 28,047	10.30	3.66	19.38
Number=505	$ (36,259)	(13.88)	(1.16)	(11.68)
Helmet Worn	$ 26,711	9.55	3.63	20.50
Number=49	$ (36,724)	(11.49)	(1.33)	(14.6)
Missing Helmet Information	$ 33,479	12.02	3.80	19.59
Number=64	$ (102,088)	(33.14)	(.87)	(8.76)

Standard deviations are in parentheses.
There were no significant differences in the four outcomes with respect to helmet use category for either case selection group.

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Traumatic brain injury is defined as damage to the brain resulting from external mechanical force, such as rapid acceleration or deceleration, impact, blast waves, or penetration by a projectile.[3] Brain function is temporarily or permanently impaired and structural damage may or may not be detectable with current technology.[4].Â The most common causes of TBI in the U.S. include violence, transportation accidents, construction, and sports.[36][47] Motor bikes are major causes, increasing in significance in developing countries as other causes reduce.[48] The estimates that between 1.6 and 3.8 million traumatic brain injuries each year are a result of sports and recreation activities in the US.[Of the 3184 motorcyclists involved in police-reported crashes in Wisconsin in 1991, 2015 (63.3%) were unhelmeted and 994 (31.2%) were helmeted at the time of the crash. Helmet use was unknown for 175 (5.5%), four of whom were fatally injured; of 32 who were hospitalized, 13 incurred head injuries. Of those motorcyclists for whom helmet status was known, 545 were hospitalized and 74 died, including 55 who were unhelmeted and 19 who were helmeted. Of the 545 hospitalized, 187 (34.3%) had sustained a head injury (Table_1).Â Skull fractures and concussions are usually associated with complete recovery, but more severe injuries to the brain can result in lifelong disability (6). Fourth, this study did not control for injuries other than head injuries.