Using Linked Data to Evaluate Risk Factors for Traumatic Brain Injury to Drivers in Passenger Vehicle Crashes in Kentucky

Crash Outcome Data Evaluation System (CODES) Linked Data Application Project

Table of Contents

Acknowledgements

This study was funded by the National Highway Traffic Safety Administration (NHTSA) through a cooperative agreement under the Crash Outcome Data Evaluation System (CODES) program. The following individuals contributed to the study and/or to the creation of this report:

Michael Singleton, MS
W. Jay Christian, BS
Tim Struttmann, MPH
J. Wesley Sublett, MPH

Also, we thank the following agencies for contributing their data, knowledge, advice, and direction to the development of a CODES for Kentucky. This study would not have been possible without their cooperation and support.

Federal Highway Administration
Kentucky Cabinet for Health Services, Department for Public Health

- Emergency Medical Services Branch
- Health Policy Development Branch

Kentucky State Police, Highway Safety Branch
Kentucky State Police, Records Section
Kentucky Transportation Cabinet
Kentucky Transportation Center
Kosair Childrens' Hospital Trauma Registry
University of Kentucky Hospital Trauma Registry
University of Louisville Hospital Trauma Registry

Executive Summary

Motor vehicle crashes were the cause of more than one-third of known cases of traumatic brain injury (TBI) in Kentucky in 1997. This retrospective, case-control study identifies several factors that are associated with an increased risk of TBI among crash-involved drivers of passenger vehicles.

- Drivers of vehicles that sustained disabling damage in crashes were nearly 16 times more likely to experience TBI than drivers of vehicles that did not.
- Drivers who required extrication from their vehicles were 11 times more likely to experience TBI than those who did not.
- Drivers who were partially ejected from their vehicles were nearly 11 times more likely to experience TBI than those who were not ejected. Those who were completely ejected were 5 times more likely to experience TBI than those who were not ejected.
- Drivers who crashed in rural areas were 1.3 times more likely to experience TBI than drivers who crashed in urban areas.
- Drivers who crashed while under the suspected influence of alcohol and/or drugs were 1.7 times more likely to experience TBI than crash-involved drivers who were reported not under the influence.
- Drivers who crashed on roadways having posted speed limits of 55 miles per hour (mph) were twice as likely to experience TBI as were drivers who crashed on roadways having posted speed limits other than 55 mph.
- Drivers aged 45-64 who crashed were 1.6 times more likely to experience TBI than drivers in a reference group (drivers aged 25-44) who crashed. Drivers aged 65 and over who crashed were 1.8 times more likely to experience TBI than drivers in the reference group who crashed.

Disabling vehicle damage (DVD) is a major risk factor for motor vehicle-related TBI, presumably because it is closely related to the amount of force generated by the collision. DVD was found to have a greater than average likelihood of occurrence in rural crashes; crashes involving drivers aged 16-24; crashes in “2-door”, “3-door”, “convertible”, and “sedan” vehicle body types; many kinds of collisions with fixed objects; “overturned” and “ran off roadway” crashes; crashes involving unsafe speed; crashes involving alcohol; crashes on roadways having speed limits of 55 and 65 mph; and crashes on state highways, county and local roads, and parkways.

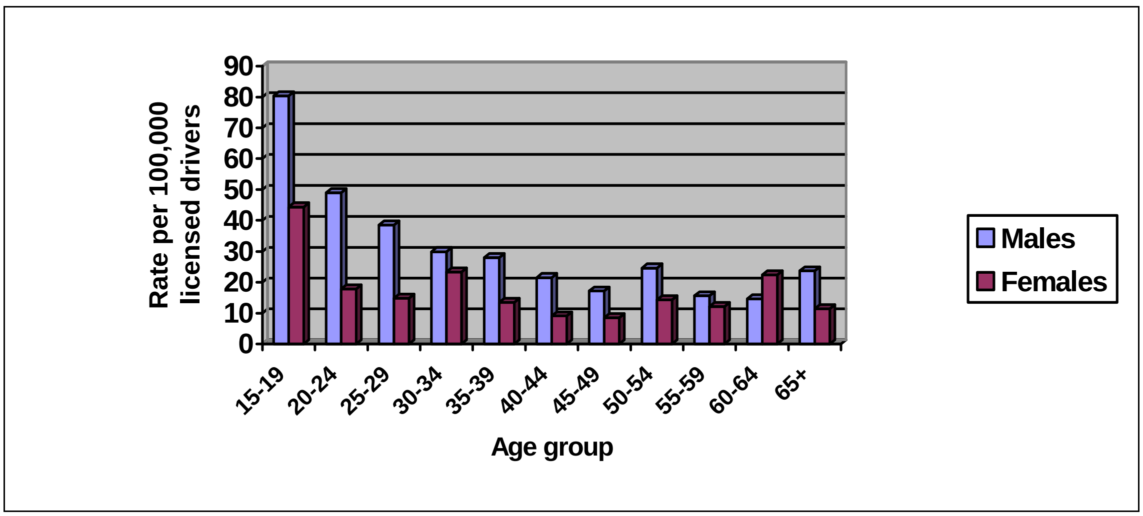
Reported seatbelt use by drivers was found to decrease the risk of TBI by 70% compared to those with no reported seatbelt use. Also, drivers of crashes with one passenger and 2-3 passengers were 30% and 35%, respectively, less likely to experience TBI than those drivers who were alone at time of crash. *It is important to note, however, that the presence of **teenage** passengers has been shown in other studies to **increase** the crash risk for teenage drivers.*

Introduction

The National Center for Injury Prevention and Control (NCIPC) estimates that each year in the United States, one million people are treated for TBI and released from hospital emergency departments; 230,000 people are hospitalized for TBI and survive; and 50,000 people die as a result of TBI. The latter figure represents nearly one-third of all injury deaths in the U.S. The leading cause of TBI in the U.S. among persons aged 5 to 64 years is motor vehicle crashes (MVC)[1]. Figure 1 shows 1997 Kentucky rates per 100,000 licensed drivers for motor vehicle-related TBI (MV-TBI). The rate for males was higher in all age groups except 60-64, and generally declined as driver age increased until age 60.

A number of studies using various methods have been conducted for the purpose of determining the rate of TBI in various states, and in the U.S. as a whole. There is considerable agreement among these studies, with the annual rate of TBI consistently reported as being between 100 and 102 cases per 100,000 annually. This rate has declined steadily and dramatically over the past twenty years. Most sources cite changing hospital admission practices for mild TBI's as a significant cause of this decrease. It is believed that mild cases, which constitute more than 50% of all TBI's over that period, are increasingly being treated on an outpatient basis. Injury prevention efforts, particularly those related to MVC's, are also cited as contributing to the decrease.[1-3]

Figure 1. Motor vehicle-related TBI rates in Kentucky by age group and gender, 1997



Data source: Kentucky linked Crash-TBI data, 1997

In Kentucky, TBI surveillance efforts have been underway since 1997. Cases have been identified using inpatient hospital discharges, trauma registries from the medical centers at the Universities of Kentucky and Louisville, and multiple-cause-of-death files from the National Center for Health Statistics (NCHS). Probabilistic data linkage has been used to identify and merge duplicate information to eliminate multiple counting of the same injury. In 1997, 3,160 cases were identified using this methodology, a rate of 86 cases per 100,000 Kentucky residents. 1,160 (37%) of the identified cases had an ICD-9 e-code indicating that a motor vehicle crash (MVC) was the mechanism of injury. The true percentage due to MVC's is probably higher, because over one-quarter of the TBI cases were missing e-codes. Lack of emergency department data probably explains most of the difference between the Kentucky rate and the rates found in the studies cited above.

Table 1. Hospital charges and injury outcomes for crash-involved drivers with MV-TBI in Kentucky, 1997*

Age group	MV-TBI	Average hospital charges	Total hospital charges	Number police reported died at scene	Percent police reported died at scene	Number discharged from hospital alive	Died in hospital
<16	4	-	-	-	-	-	-
16-19	104	$4,075	$423,800	27	26%	36	0
20-24	79	$6,434	$508,286	26	33%	33	1
25-29	67	$8,476	$567,892	13	19%	37	1
30-34	68	$7,386	$502,248	17	25%	35	0
35-39	57	$4,019	$229,083	21	36%	21	0
40-44	41	$7,575	$310,575	13	31%	17	0
45-49	33	$12,439	$410,487	14	42%	10	0
50-54	39	$15,359	$599,001	7	17%	22	0
55-59	23	$2,553	$58,719	8	35%	9	0
60-64	21	$11,320	$237,720	1	5%	11	0
65+	63	$8,426	$530,838	19	30%	23	1
Missing	4	-	-	-	-	-	-
Total	**603**	**-**	**$4,378,649**	**167**	**27%**	**254**	**3**

Data source: Kentucky linked Crash-TBI data, 1997

*The sum of "died at scene," "discharged alive," and "died in hospital" does not equal the total number of MV-TBI due to missing disposition data on hospital discharge records, and to linked TBI cases for which a trauma registry record was found, but no hospital discharge record was found.

In 1997, inpatient hospital charges alone for TBI admissions amounted to over $4.1 million (Table 1). This number reflects only those cases that we were able to link to a crash record, and therefore underestimates total 1997 hospital charges for MV-TBI. Also, 223 (37%) of the persons hospitalized survived their TBI. The ongoing treatment and rehabilitation costs for these survivors are not included in this analysis, but are likely to far exceed the cost of initial acute care.

Goldstein, Spurlock, and Kidd used the National Highway Traffic Safety Administration's (NHTSA) *CrashCost* software to develop cost estimates for fatal and critical injuries (i.e., those coded as "K" and "A" on the KABCO severity scale) for

MVC's occurring in Kentucky in 1994[4]. Their study estimated that the economic cost of a single fatal injury was $642,700, and for a critical injury $563,000[*]. Given that 167 of the MV-TBI injuries in 1997 were fatal, and another 281 were critical (based on police-reported injury severity), the total economic cost of MV-TBI in Kentucky for 1997 using these cost estimates can be placed at $262 million. According to a separate study done by the National Institutes of Health, estimates for average lifetime cost of care for a person with severe TBI range from $600,000 to $1,875,000[2].

However one calculates the costs, TBI is a major public health problem in the United States and worldwide. Motor vehicle crashes are the leading cause of TBI in Kentucky. A clear understanding of the human, vehicular, and environmental factors that affect the risk of these injuries is important for the effective utilization of prevention resources.

Methods

<u>Data sources</u>

Kentucky Accident Reporting System (KARS)

The KARS database contains electronic records of all motor vehicle crashes investigated by law enforcement agencies in Kentucky. Kentucky law requires that all motor vehicle collisions which involve the injury of any person, or which render any vehicle inoperable, be investigated by a law enforcement agency having jurisdiction over the area in which the collision occurred (KRS 189.635).

Inpatient hospital discharge data

Kentucky has a population-based hospital discharge reporting system based on the federal Universal Billing-1992 standard. A law enacted during the 1994 legislative session mandated submission of these forms, and reporting began January 1, 1995. The system is administered by the Health Policy Analysis Branch of the Kentucky Department for Public Health.

The reporting threshold is any person who is hospitalized in the state of Kentucky, "regardless of whether a bill is to be generated or the services are to remain unbilled." (KAR 17:040 - Data reporting by health care providers. This regulation excludes from the definition of a "hospitalization" the following: "inpatient services a hospital may provide in swing, dual licensed, nursing facility, skilled, intermediate or personal care beds, hospice, and major ambulatory procedures, notwithstanding that these may occur in hospitals.")

[*] *CrashCost* estimates include direct costs, such as emergency services, initial medical costs, rehabilitation costs, long-term care and treatment, insurance administration expenses, legal costs, and employer/workplace costs; and indirect costs, such as productivity losses in the workplace and home due to temporary and permanent disability. Productivity losses account for over 80% of the cost estimates quoted here.

Compliance is required of all hospitals statewide. However, facilities have had varying levels of success implementing the system, and 20% of hospitals in Kentucky were not yet reporting in 1997.

Trauma registries data

There are two Level I trauma facilities in Kentucky: the medical centers at the Universities of Kentucky and Louisville. Each is required to maintain a patient registry based on the American College of Surgeons' National Trauma Data Bank criteria.

Multiple-cause-of-death data

The Kentucky death certificates database includes all deaths of Kentucky residents, whether the death occurred within the Commonwealth or elsewhere. Compliance is essentially 100 percent for this file. Only deaths unknown to authorities are not entered, and this is not a factor in motor vehicle crash-related deaths.

Kentucky participates in the NCHS national vital statistics data system. NCHS provides additional analysis of causes of death, and adds two sets of up to twenty additional ICD-9 diagnoses codes to the death record. These diagnoses are essential for defining cases of death due to TBI using the Centers for Disease Control (CDC) standard case definition, because the Kentucky vital statistics office provides only a primary cause of death and up to three supplemental causes.

Creation of TBI data set

A merged data set containing all recorded cases of TBI in Kentucky during the year 1997 was created. TBI victims were abstracted from inpatient hospital discharge data, trauma registries data, and NCHS multiple-cause-of-death data for the year 1997. TBI was defined using the CDC standard definition, which consists of the following ICD-9 diagnosis codes:

800.0 – 801.9	Fracture of vault or base of skull
803.0 – 804.9	Other, unqualified, and multiple fractures of skull
850.0 – 854.1	Intracranial injury, including concussion, cerebral laceration, subdural hemorrhage, unspecified intracranial injury, etc.

All available diagnosis code fields for each data set were searched. TBI cases were identified when any diagnosis code field met the CDC definition of TBI. Duplicate records, which arose from overlap in the data sources, were identified using probabilistic linkage. Variables used in the probabilistic linkage were age, county of injury, county of residence, date of birth, date of death, date of hospital discharge, gender, race, and zip code of residence. The probabilistic linkage was performed using Automatch software, version 4.2. Identified duplicates were merged to form a single record for each distinct TBI event. The final TBI data set contained 3,160 cases.

In 1997, approximately 20% of hospitals failed to report discharges. Also, there is no statewide collection of emergency department data in Kentucky at present. Therefore, cases treated and released from a hospital that failed to report discharges, or in an ED setting, are not included in the TBI data set.

<u>Linkage of TBI and crash data sets</u>

Preparation of crash data set

The crash data set was prepared for linkage by removing records for non-drivers, commercial vehicles, and motorcycles. That is, the linkable crash data set contained only records pertaining to drivers of passenger vehicles, including pickups, sport utility vehicles, and vans. We chose to restrict the crash data set in these ways for the following reasons. (1) Date of birth is a key variable for obtaining accurate linkages, but in Kentucky law enforcement officers do not collect dates of birth for passengers. Thus, for passengers there is a significantly higher probability of either failing to match a crash record when in fact it has a match (a false negative match), or incorrectly matching a crash record which does not in fact have a match (a false positive match). Both of these occurrences amount to a passenger who is misclassified with regard to TBI outcome. Restricting the study to drivers allows us to eliminate this source of error. It also eliminates the confounding effect of seating position. (2) In order to eliminate variances due to the differences among passenger vehicles, commercial vehicles, and motorcycles, we elected to restrict the study to passenger vehicles rather than control for vehicle type. Passenger vehicles were identified by the vehicle body type codes listed in Appendix A.

Linkage process

After deletion of crash records for passengers and non-passenger vehicles, there were 212,907 remaining. Preparation of the TBI file from hospital discharges, trauma registries, and death certificates yielded 3,160 cases of TBI from all causes. These two files were linked, with 603 matched crash-TBI records resulting. Variables used in the probabilistic linkage were age, county of residence, date of birth, date of crash, e-code, gender, hospital code, date of crash/admission/death, and time of crash/admission/death. Linked crash records were coded as having a "TBI" outcome; unlinked crash records were coded as having a "no TBI" outcome.

598 of the 3,160 TBI cases were identified as drivers of motor vehicles based on e-codes. All of these should link to a crash record, unless the crash occurred outside of Kentucky and the person was transported to a hospital in Kentucky for treatment. 509 (85%) of these motor vehicle driver TBI's linked to a crash record. The false negative rate for this linkage is therefore estimated to be 15%. Twenty-one TBI records having non-motor vehicle e-codes linked to a crash record. If these are all incorrect matches, our estimated false positive match rate is 3.5%. Seventy-three of the linked TBI cases had missing e-codes.

Case-control methods

Case and control groups were selected from the linked data set. It was decided at this point that the analysis should be limited to Kentucky drivers. As a result, drivers with a state of residence other than Kentucky on their license were dropped from the linked crash-TBI data set (n=26,276). Cases of TBI were defined as passenger vehicle drivers with a documented vehicle crash and identified occurrence of TBI. Controls were defined as all passenger vehicle drivers with a documented vehicle crash and no identified TBI.

Potential risk factors were identified from the crash literature. The identified risk factors were compared against the data available in the data set. Those available factors include age, collision type, crash location, drunk driving, ejection, extraction, lighting conditions, number of occupants, seatbelt use, sex, site of impact, speed limit, vehicle damage, vehicle overturned, vehicle size, vehicle type, and weather conditions.

Observations with missing data for potential risk factors were dropped. Miscoded and nonsense codes were treated as missing, and the observations containing them were dropped. After these deletions (n=26,267), the final data set used in the logistic regression analysis contained observations for 160,364 drivers, of which 468 were identified as TBI cases. The age and gender distributions of those 468 TBI were found to be very similar to those for all 603 linked TBI.

The relative risk of TBI in drivers of passenger vehicle crashes was estimated using odds ratios and 95% confidence intervals. Odds ratios were calculated using logistic regression. Crude estimates of risk were first calculated for each potential risk factor, and reported as crude odds ratios with 95% confidence intervals. Adjusted risk estimates were then calculated for each risk factor while controlling for all other factors.

All statistical analyses were performed using the SPSS software system, version 10.0.

Results

Table 2 reports the prevalence of risk factors in the study population.

Table 2. Risk factor frequencies for drivers of crash-involved passenger vehicles in Kentucky, 1997

Risk Factor	% Population (n=160,364)
Crash Location	
Rural	31.7
Urban	68.3
Weather	
Rain	18.0
Snow	2.5
Fog/Smoke	0.4
Sleet/Hail	0.4
Cloudy	21.7
Clear	57.0
Lighting	
Dawn	1.3
Dusk	2.5
Dark- hwy lights on	9.8
Dark- hwy lights off	0.6
Dark- no lights	7.8
Daylight	77.9
Drunk Driving	
Yes	3.0
No	97.0
Sex	
Male	54.7
Female	45.3
Extraction	
Yes	1.6
No	98.4
Ejection	
Partial	0.5
Total	0.1
No	99.4
Posted Speed Limit	
MPH ≤ 25	13.5
MPH 25-40	40.2
MPH 40-54	19.7
MPH 55	24.8
MPH 65	1.8
Vehicle Type	
Two Door	25.4
Three Door	1.1
Four Door	38.9
Pickup	22.6
Van	6.3
Sedan	1.3
Other Cars	4.4

Risk Factor	% Population (n=160,364)
Vehicle Size	
Full	38.8
Intermediate	39.0
Compact	20.0
Subcompact	2.2
Overturn	
Yes	0.4
No	99.6
Number of Occupants	
2	22.2
3-4	9.8
5-6	1.1
>6	0.1
1	66.7
Age	
<=19	14.9
20-24	14.3
45-64	19.7
>65	8.4
25-44	42.7
Seatbelt	
Yes	90.4
No	9.6
Object Struck	
Hit other vehicle	87.2
Hit earthen object	2.5
Hit animal	2.1
Hit tree	1.3
Hit other fixed object	4.3
No collision	1.6
Impact Site	
Front Impact	61.0
Right Impact	4.9
Rear Impact	27.3
Left Impact	5.6
Top Impact	0.8
Bottom Impact	0.3
Reported Damage	
Functional	44.4
Nonfunctional	19.0
Disabling	3.0
No Damage	33.7

In the sample, the majority of drivers were male (54.7%). Most (42.7%) drivers were between the ages of 25-44 years, with 14.9% of the sample 19 years or younger, 14.3% between the ages of 20-24 years, 19.7% between the ages of 45-64, and 8.4% sixty-five years or older. Seat belt use by drivers was reported in 90.4% of all crashes. Suspected DUI was reported in 3.0% of drivers involved in crashes. The majority (66.7%) of drivers were driving alone at the time of crash. Twenty-two percent of drivers had one passenger, while 9.8% had 2-3 passengers, 1.1% had 5-6 passengers, and 0.1% had more than 6 passengers at the time of crash.

Crashes occurred more frequently in urban areas (68.3%) than in rural areas (31.7%). Clear weather was reported for the majority of crashes (57.0%). Other weather conditions reported in crashes are 21.7% in cloudy conditions, 18% in rain, 2.5% in snow, 0.4 in fog/smoke, and 0.4% in sleet/hail. The majority of crashes occurred in daylight lighting conditions, with 1.3% occurring in dawn lighting conditions, 2.5% occurring in dusk lighting conditions, 9.8% occurring in dark with highway lights on, 0.6% occurring in dark with highway lights off, and 7.8% occurring in dark with no highway lights. A posted speed limit between 26-40 mph was reported in 40.2% of crashes. Crashes also occurred at posted speed limits of 25 mph or less (13.5%), 40-54 mph (19.7%), 55 mph (24.8%), and 65 mph (1.8%).

Vehicle types that comprised the sample were 25.4% two-doors, 1.1% three-doors, 38.9% four-doors, 22.6% pickups, 6.3% vans, 4.4% sedan, and 1.3% other type. Vehicle size was reported being 38.8% full size, 39.0% intermediate size, 20.0% compact, and 2.2% sub-compact.

Type of crash percentages are reported in the sample as follows: 87.2% hit other vehicle; 2.1% hit an animal; 2.5% hit earthen object; 1.3% hit a tree; 4.3% hit other fixed object; 1.6% no collision crash. Front impact was reported in the majority of crashes (61%). Other impacts were reported as 27.3% rear, 4.9% right-side, 5.6% left-side, and 0.8% top. Overturn was reported in 0.4% of the sample.

In crashes, the damage severity most commonly recorded was functional (44.4%). No damage was recorded for 33.7% of crashes. Nonfunctional and disabling were recorded 19.0% and 3.0%, respectively. Extrications were reported in 1.6% of crashes, while partial and full ejection of drivers were reported at 0.5% and 0.1%, respectively.

Table 3 reports the results of the unadjusted odds for all risk factors. Unadjusted odds ratios identified 36 significant risk factors. Male drivers involved in passenger vehicle crashes were more likely (OR= 1.34; CI= 1.11, 1.62) to have an occurrence of TBI compared to female drivers. Drivers aged ≤ 19 years and ≥ 65 years show a marginal increase in risk for TBI with odds ratios of 1.39 (CI=1.07, 1.80) and 1.47 (CI=1.08, 2.01) respectively compared to drivers between the ages of 25-44 years. The risk of TBI increases significantly in drivers found to be under the influence of alcohol or drugs (OR=10.93; CI=8.84, 13.52). Seat belt use by drivers results in a significant decreased risk of TBI (OR=0.08, CI=0.07, 0.10). Drivers with one passenger (OR=0.77; CI=0.61, 0.97) or 2-3 passengers (OR=0.63; CI= 0.44, 0.91) show a marginally decreased risk of TBI compared to those drivers who were alone at time of crash.

Table 3. Crude odds ratios for TBI in drivers of crash-involved passenger vehicles in Kentucky, 1997

Risk Factor	% Controls (n=159896)	% Cases (n=468)	OR	95% CI Lower	95% CI Upper	p
Crash Location						
Rural	31.6	69.9	5.02	4.12	6.11	0.00
Urban			Reference			
Weather						
Rain	18.0	17.7	0.97	0.76	1.24	0.79
Snow	2.5	2.1	0.85	0.45	1.60	0.61
Fog/Smoke	0.4	2.1	4.83	2.56	9.12	0.00
Sleet/Hail	0.4	0	0.03	0.00	125.33	0.42
Cloudy	21.7	20.1	0.91	0.72	1.15	0.43
Clear	57.0	57.9	Reference			
Lighting						
Dawn	1.3	2.6	2.38	1.34	4.25	0.00
Dusk	2.5	1.9	0.93	0.48	1.81	0.84
Dark- hwy lights on	9.8	5.1	0.64	0.42	0.97	0.04
Dark- hwy lights off	0.6	1.3	2.50	1.11	5.62	0.03
Dark- no lights	7.8	25.9	4.10	3.32	5.07	0.00
Daylight	77.9	63.2	Reference			
Drunk Driving						
Yes	2.9	24.6	10.93	8.84	13.52	0.00
No			Reference			
Sex						
Male	54.6	61.8	1.34	1.11	1.62	0.00
Female			Reference			
Extraction						
Yes	1.5	44.4	52.58	43.63	63.38	0.00
No						
Ejection						
Partial	0.4	13.0	37.76	28.52	49.99	0.00
Total	0.1	5.1	60.78	39.15	94.36	0.00
No			Reference			
Posted Speed Limit						
MPH ≤ 25	13.5	4.5	0.30	0.19	0.47	0.00
MPH 25-40	40.2	15.0	0.26	0.20	0.34	0.00
MPH 40-54	19.7	12.0	0.55	0.42	0.73	0.00
MPH 55	24.7	66.2	5.98	4.93	7.24	0.00
MPH 65	1.8	2.4	1.33	0.73	2.41	0.36
Vehicle Type						
Two Door	25.4	26.5	1.06	0.86	1.30	0.58
Three Door	1.1	2.4	2.14	1.18	3.90	0.01
Four Door	38.9	39.3	1.02	0.84	1.22	0.87
Pickup	22.6	23.7	1.07	0.86	1.32	0.56
Van	6.3	3.0	0.46	0.27	0.78	0.00
Sedan	4.4	4.1	0.92	0.58	1.46	0.72
Other Cars	1.3	1.1	0.85	0.35	2.06	0.72
Vehicle Size						
Full	38.8	32.7	0.77	0.63	0.93	0.01
Intermediate	39.0	43.4	1.20	1.00	1.44	0.05
Compact	20.0	20.5	1.03	0.82	1.29	0.80
Subcompact	2.2	3.4	1.61	0.97	2.65	0.06
Overturn						
Yes	0.4	3.0	8.04	4.70	13.76	0.00
No			Reference			
Number of Occupants						
2	22.2	18.8	0.77	0.61	0.97	0.03
3-4	9.8	6.8	0.63	0.44	0.91	0.01
5-6	1.1	0.4	0.34	0.09	1.36	0.13

Risk Factor	% Controls (n=159896)	% Cases (n=468)	OR	95% CI Lower	95% CI Upper	p
Number of Occupants						
>6	0.1	0.2	1.62	0.23	11.58	0.63
1	66.7	73.7	Reference			
Age						
<=19	14.8	18.2	1.39	1.07	1.80	0.01
20-24	14.3	13.5	1.07	0.80	1.43	0.65
45-64	19.7	19.9	1.14	0.89	1.47	0.30
>65	8.4	10.9	1.47	1.08	2.01	0.02
25-44	42.7	37.6	Reference			
Seatbelt						
Yes	90.5	44.2	0.08	0.07	0.10	0.00
No			Reference			
Object Struck						
Hit other vehicle	87.3	54.3	0.17	0.14	0.21	0.00
Hit earthen object	2.5	11.3	5.08	3.81	6.77	0.00
Hit animal	2.1	0.6	0.31	0.10	0.95	0.04
Hit tree	1.3	9.0	7.61	5.53	10.49	0.00
Hit other fixed object	4.2	16.9	4.59	3.60	5.85	0.00
No collision	1.6	7.1	4.60	3.22	6.56	0.00
Impact Site						
Front Impact	61.0	69.2	1.44	1.18	1.75	0.00
Right Impact	4.9	7.7	1.61	1.14	2.26	0.01
Rear Impact	27.3	7.1	0.20	0.14	0.29	0.00
Left Impact	5.6	10.5	1.97	1.46	2.65	0.00
Top Impact	0.8	5.3	7.04	4.69	10.58	0.00
Bottom Impact	0.3	0.2	0.66	0.09	4.72	0.68
Reported Damage						
Functional	33.8	7.1	2.93	0.40	21.40	0.29
Nonfunctional	44.5	3.2	1.01	0.13	7.65	0.99
Disabling	18.7	89.5	66.94	9.41	476.41	0.00
No Damage	3.0	0.2	Reference			

A significant increase in risk of TBI is shown for crashes in rural areas (OR=5.02; CI=4.12, 6.11) compared to those crashes in urban areas. Fog/Smoke reported for crashes results in a significant increase in TBI (OR=4.83; CI=2.56, 9.12) compared to crashes during clear weather. Unadjusted odds ratios for lighting conditions show significant risk for TBI in crashes. Lighting at dawn results in an increased risk of TBI (OR=2.38; CI=1.34, 4.25). Crashes in dark lighting conditions shows mixed results for risks. Odds ratios for crashes in dark lighting conditions with highway lights off or with no lights present show an increase in risk of TBI with odds ratios of 2.50 (CI=1.11, 5.62) and 4.10 (CI=3.32, 5.07) respectively. Crashes in dark lighting conditions with highway lights on show a marginal decrease in risk of TBI with an odds ratio of 0.64 (CI=0.42, 0.97). Posted speed limits were also shown to be significantly associated with TBI in crashes. Posted speed limits of 40-54 mph, 25-40 mph, and ≤25 mph show a decreased risk of TBI in crashes with odds ratios of 0.55 (CI=0.42, 0.73), 0.26 (CI=0.20, 0.34), and 0.30 (CI=0.19, 0.47) respectively. A posted speed limit of 55 mph increases the risk of TBI with a reported odds ratio of 5.98 (CI=4.93, 7.24).

Three door vehicles show an increased risk of TBI in crashes (OR=2.14; CI=1.18, 3.90) while vans show a decreased risk with an odds ratio of 0.46 (CI= 0.27, 0.78). Also, full size vehicles reported a decrease in risk (OR=0.77; CI=0.63, 0.93).
Drivers involved in collisions with other vehicles (OR=0.17; CI=0.14, 0.21) or animals (OR=0.31; CI=0.10, 0.95) were less likely to have a TBI. Collisions with earthen objects

(OR=5.08; CI=3.81, 6.77), trees(OR=7.61; CI=5.53, 10.49), and other fixed objects (OR=4.59; CI=3.60, 5.85) show increased risk of TBI for drivers. Crashes with no collision (OR=4.60; CI=3.22, 6.56) also show an increase risk of TBI. Front (OR=1.44; CI=1.18, 1.75), left (OR=1.97; CI=1.46, 2.65), right (OR=1.61; CI=1.14, 2.26), and top (OR=7.04; CI=4.69, 10.58) impact sites increase the risk of TBI where as rear (OR=0.20; CI=0.14, 0.29) impact is shown to be protective. Vehicle overturn (OR=8.04; CI=4.70, 13.76) also reports an increase in risk of TBI.

Car damage classified as disabling was strongly associated with an increase risk of TBI in crashes reporting an odds ratio of 66.94 (CI=9.41, 476.41). Reported extrication shows an increase in risk with an odds ratio of 52.58 (CI=43.63, 63.38). Drivers who are partially (OR=37.76; CI=28.52, 49.99) or totally (OR=60.78; CI=39.15, 94.36) ejected from the vehicle are also more likely to have a TBI.

Adjusted risk estimates, presented in Table 4, were calculated controlling for all other risk factors. Twelve risk factors had significant adjusted odds ratios. Drivers aged 45-64 years and ≥ 65 years show an increase in risk for TBI with adjusted odds ratios of 1.55 (CI=1.18, 2.04) and 1.77 (CI=1.25, 2.50) respectively compared to drivers of passenger vehicle crashes between the ages of 25-44 years. The risk of TBI also increases significantly in drivers found to be under the influence of alcohol or drugs (aOR=1.71; CI=1.28, 2.28). A significant decrease in risk of TBI is seen in drivers with reported seatbelt use (aOR=0.34, CI=0.27, 0.42). Drivers with one passenger (aOR=0.77; CI=0.60, 0.99) or 2-3 passengers (aOR=0.65; CI= 0.44, 0.95) show a marginally decreased risk of TBI compared to those drivers who are alone at time of crash.

Crashes in rural areas are more likely to have occurrence of TBI than those in urban areas (aOR=1.31; CI= 1.01, 1.69). Also, TBI increases significantly in areas with a posted speed limit of 55 mph (aOR=2.03; CI= 1.07, 3.83).

An adjusted odds ratio of 15.73 (CI=2.17, 113.93) was reported for car damage classified as disabling. Reported extrication shows an increase in risk with an adjusted odds ratio of 10.69 (CI=8.62, 13.26). Ejection was also significantly associated with TBI. Drivers who experienced partial ejection were approximately 10.5 times more likely (aOR=10.62; CI=7.47, 15.09) to have an occurrence than those who were not ejected. Total ejection also shows an increase in risk of TBI with an adjusted odds ratio of 4.99 (CI= 2.84, 8.76)

Table 4. Adjusted odds ratios for TBI in drivers of crash-involved passenger vehicles in Kentucky, 1997

Risk Factor	% Controls (n=159896)	% Cases (n=468)	aOR	95% CI Lower	95% CI Upper	p
Crash Location						
Rural	31.6	69.9	1.31*	1.01	1.69	0.04
Urban			Reference			
Weather						
Rain	18.0	17.7	1.1	0.85	1.43	0.48
Snow	2.5	2.1	0.78	0.4	1.51	0.46
Fog/Smoke	0.4	2.1	1.57	0.76	3.27	0.23
Sleet/Hail	0.4	0	0	0	828037	0.57
Cloudy	21.7	20.1	1.04	0.81	1.34	0.75
Clear	57.0	57.9	Reference			
Lighting						
Dawn	1.3	2.6	1	0.52	1.94	1.00
Dusk	2.5	1.9	0.7	0.34	1.43	0.33
Dark- hwy lights on	9.8	5.1	0.66	0.41	1.04	0.07
Dark- hwy lights off	0.6	1.3	1.12	0.44	2.81	0.81
Dark- no lights	7.8	25.9	1.11	0.85	1.44	0.46
Daylight	77.9	63.2	Reference			
Drunk Driving						
Yes	2.9	24.6	1.71*	1.28	2.28	0.00
No			Reference			
Sex						
Male	54.6	61.8	1.04	0.84	1.3	0.69
Female			Reference			
Extraction						
Yes	1.5	44.4	10.69*	8.62	13.26	0.00
No			Reference			
Ejection						
Partial	0.4	13.0	10.62*	7.47	15.09	0.00
Total	0.1	5.1	4.99	2.84	8.76	0.00
No			Reference			
Posted Speed Limit						
MPH $\leq$ 25	13.5	4.5	1.15	0.53	2.5	0.73
MPH 25-40	40.2	15.0	0.99	0.5	1.97	0.98
MPH 40-54	19.7	12.0	1.33	0.66	2.66	0.42
MPH 55	24.7	66.2	2.03*	1.07	3.83	0.03
MPH 65	1.8	2.4				
Vehicle Type						
Two Door	25.4	26.5	0.74	0.29	1.87	0.52
Three Door	1.1	2.4	1.51	0.5	4.57	0.47
Four Door	38.9	39.3	0.95	0.38	2.38	0.91
Pickup	22.6	23.7	0.61	0.24	1.54	0.29
Van	6.3	3.0	0.61	0.21	1.78	0.37
Sedan	4.4	4.1	0.58	0.21	1.62	0.3
Other Cars	1.3	1.1				
Vehicle Size						
Full	38.8	32.7	0.59	0.34	1.03	0.06
Intermediate	39.0	43.4	0.75	0.43	1.3	0.31
Compact	20.0	20.5	0.67	0.38	1.19	0.17
Subcompact	2.2	3.4				
Overturn						
Yes	0.4	3.0	1.26	0.57	2.79	0.57
No			Reference			
Number of Occupants						
2	22.2	18.8	0.77*	0.6	0.99	0.04
3-4	9.8	6.8	0.65*	0.44	0.95	0.03

Risk Factor	% Controls (n=159896)	% Cases (n=468)	aOR	95% CI Lower	95% CI Upper	p
5-6	1.1	0.4	0.28	0.07	1.16	0.08
>6	0.1	0.2	1.28	0.16	10.1	0.82
1	66.7	73.7	Reference			
Age						
<=19	14.8	18.2	1.14	0.85	1.51	0.38
20-24	14.3	13.5	0.89	0.65	1.21	0.45
45-64	19.7	19.9	1.55*	1.18	2.04	0.00
>65	8.4	10.9	1.77*	1.25	2.5	0.00
25-44	42.7	37.6	Reference			
Seatbelt						
Yes	90.5	44.2	0.34*	0.27	0.42	0.00
No			Reference			
Object Struck						
Hit other vehicle	87.3	54.3	0.52	0.18	1.51	0.23
Hit earthen object	2.5	11.3	0.26	0.06	1.25	0.09
Hit animal	2.1	0.6	0.59	0.2	1.77	0.35
Hit tree	1.3	9.0	0.56	0.19	1.7	0.31
Hit other fixed object	4.2	16.9	0.79	0.27	2.32	0.67
No collision	1.6	7.1	0.53	0.17	1.71	0.29
Impact Site						
Front Impact	61.0	69.2	2.47	0.32	18.86	0.38
Right Impact	4.9	7.7	3.54	0.45	27.83	0.23
Rear Impact	27.3	7.1	1.9	0.24	14.95	0.54
Left Impact	5.6	10.5	3.63	0.46	28.39	0.22
Top Impact	0.8	5.3	2.25	0.28	17.93	0.44
Bottom Impact	0.3	0.2				
Reported Damage						
Functional	33.8	7.1	1.89	0.26	13.96	0.53
Nonfunctional	44.5	3.2	0.93	0.12	7.06	0.94
Disabling	18.7	89.5	15.73*	2.17	113.93	0.01
No Damage	3.0	0.2	Reference			

.

Discussion

Disabling vehicle damage (DVD), extrication from the vehicle, and ejection from the vehicle are associated with significantly increased risk of TBI for crash-involved drivers of passenger vehicles. It is therefore important to investigate the human, vehicular, and environmental circumstances that are associated with the occurrence of these events.

Disabling vehicle damage (DVD)

The risk of TBI for drivers of passenger vehicle crashes was found to be greatest in crashes that reported disabling vehicle damage. For crash coding purposes, DVD is defined as damage that renders a vehicle inoperable. Drivers in vehicles with DVD were nearly 16 times more likely to have an occurrence of TBI than were drivers of vehicles with no recorded damage.

Crash location – rural vs. urban

Crashes occur less frequently in rural areas than in urban areas, but they are more severe when they do occur. Gabella, Hoffman, Marine and Stallones found that a considerable difference exists in the rate of MV-TBI in urban and rural areas in Colorado. The MV-TBI rate for the Denver-Boulder Metropolitan Statistical Area was 14.8 per 100,000 residents. In rural areas it was 25 per 100,000[6].

Of the vehicles in our study population, the frequency of DVD was almost equal between rural (15,053 or 49.5%) and urban (15,343 or 50.5%) areas. However, 68% of the total vehicles in the sample crashed in urban areas, whereas 32% crashed in rural areas. Viewed another way, 14% of vehicles that crashed in urban areas sustained DVD, compared to nearly 30% of the vehicles that crashed in rural areas. An important reason for this difference in crash severity between rural and urban locations is the combination of high speeds with two-lane roadways.

Engineering interventions can reduce the frequency and severity of rural crashes. The Kentucky Transportation Center found that both (a) converting two-lane rural roads to four lanes, and (b) upgrading two-lane rural roads with realignment and wider lanes and shoulders, dramatically reduced the number and rate of fatal and injury crashes[7].

Type of first harmful event

The majority of crashes – nearly 73% - involving DVD are collisions with other motor vehicles (Table 5). However, only 15.8% of all vehicles that crashed with another motor vehicle resulted in DVD. Other types of collision occur less frequently, but are more likely to result in DVD. For example, vehicles that crashed into trees comprised only 4.4% of all vehicles that sustained DVD, but when a vehicle *did* impact with a tree, there was DVD nearly 64% of the time.

Table 5. Relationship between first harmful event and disabling vehicle damage for crash-involved drivers in Kentucky, 1997

First harmful event or impact	Number of vehicles having DVD	Percent of all vehicles having DVD	Percent of all vehicles in this type of crash having DVD
Motor vehicle	22,159	72.9	15.8
Earth	1,923	6.3	48.4
Tree	1,325	4.4	63.5
Light	752	2.5	57.7
Ran off roadway	611	2.0	44.7
Overturn	458	1.5	73.3
Guard rail	434	1.4	41.1
Culvert head	170	1.0	61.8
Median/barrier	170	0.6	52.6
Guard rail end	100	0.3	45.5
Other	2,294	7.1	-
Total	**30,396**	**100.0**	**19.0**

Data source: Kentucky linked crash-TBI data, 1997

This suggests that there are significant opportunities for interventions to reduce TBI by reducing the amount of vehicle damage sustained in crashes with fixed objects. Trees and light poles may need to be moved farther from roadways, for example. The specific circumstances contributing to motor vehicle vs. motor vehicle crashes that result in DVD need to be investigated as well.

Human contributing factors

Unsafe speed and alcohol involvement played a significantly larger role in DVD crashes than in non-DVD crashes. Unsafe speed was cited in 9.7% of vehicles in DVD crashes, compared to 4.2% of all vehicles in the study population. Alcohol involvement was reported in 4.7% of vehicles in DVD crashes, compared to 1.8% of all vehicles. Both of these turned out to be risk factors independent of whether there was disabling vehicle damage. Speed is discussed next, and alcohol involvement is examined later under "Other risk factors."

Posted speed limit and highway type

Speed is a risk factor for TBI, but high speeds are more dangerous on certain kinds of roadways than on others. As Table 6 shows, there was very little difference in the proportion of vehicles sustaining DVD – nearly one third - in crashes that occurred at speed limits of 55 mph and 65 mph. Among all vehicles in the study population that sustained DVD, only 3% of these crashed at a PSL of 65 mph. Forty-two percent crashed at a PSL of 55 mph, and *27% crashed at a PSL of 35 mph.*

Table 6. Relationship between posted speed limit and disabling vehicle damage for crash-involved drivers in Kentucky, 1997

Posted speed limit (mph)	Number of vehicles having DVD	Percentage of all vehicles having DVD that crashed at this PSL	Percentage of only those vehicles that crashed at this PSL that sustained DVD
55	12,851	42.3	32.3
35	8,253	27.2	14.2
45	5.393	17.7	17.6
25	1,830	6.0	9.5
65	912	3.0	31.9
Other	1,157	3.8	-
Total	**30,396**	**100.0**	**19.0**

Data source: Kentucky linked crash-TBI data, 1997

From Table 7 we see that vehicles that crash on state highways and county/local roads – where the posted speed limit is usually 35-55 mph - sustain DVD at higher percentages than do vehicles that crash on interstates, where the posted speed limits of 65 mph are the rule. Consideration should be given to increasing law enforcement presence, as well as the severity of penalties for speeding and other infractions, on roadways where the severe crash rate is greatest, irrespective of the posted speed limit. In addition, legislation should be enacted to add a fine to citations on such roadways that would be used to fund motor vehicle-related TBI prevention, research, and rehabilitation.

Table 7. Relationship between roadway type and disabling vehicle damage for crash-involved drivers in Kentucky, 1997

Type of roadway	Number of vehicles having DVD	Percentage of all vehicles having DVD that crashed on this type of roadway	Percentage of only those vehicles that crashed on this type roadway that sustained DVD
State highway	12,281	40.4	22.6
Federal highway	9,120	30.0	18.7
Local street	5,655	18.6	12.9
County/local	1,605	5.3	29.2
Interstate	1,392	4.6	19.7
Parkway	343	1.1	34.3
Total	**30,396**	**100.0**	**19.0**

Data source: Kentucky linked crash-TBI data, 1997

Driver age

Drivers aged 16-24 were more likely than other drivers to be involved in crashes in which their vehicle sustained disabling damage (Table 8). DVD occurred in 24.8% of crash-involved vehicles driven by 16-19 year olds, and 21.5% of those driven by 20-24 year olds. For all other drivers the average was 17.2%. This means that crashes among drivers in these groups result in severe vehicle damage more often than for other age groups, and are therefore more likely to result in TBI. In addition, 16-24 year olds were involved in a disproportionate number of DVD crashes. Vehicles that sustained DVD were driven by 16-24 year olds in 35.8% of cases, but that age group accounted for only 14.1% of all Kentucky licensed drivers in 1997. Determination of the factors that contribute to increased DVD in this age group will help target TBI prevention resources more effectively.

Table 8. Relationship between driver age and disabling vehicle damage for crash-involved drivers in Kentucky, 1997

Age	Number of vehicles having DVD	Percent of all vehicles having DVD	Percent of vehicles having DVD for this age group
16-19	5,916	19.4	24.8
20-24	4,939	16.3	21.5
25-29	3,623	11.9	18.8
30-34	3,240	10.7	18.3
35-39	3,020	9.9	17.7
40-44	2,302	7.6	16.0
45-49	1,889	6.2	16.3
50-54	1,357	4.5	15.7
55-59	1,005	3.3	15.4
60-64	753	2.5	15.3
65-69	749	2.5	16.8
70-74	616	2.0	16.0
75-79	538	1.8	18.7
80-84	311	1.0	19.6
85+	138	0.4	18.9
Total	**30,396**	**100.0**	**19.0**

Data source: Kentucky linked crash-TBI data, 1997

Extrication

Extrication also showed a significant increase in risk, as crash-involved drivers who required extrication were 11 times more likely to have a TBI than those who did not. There is a strong relationship between the amount of vehicle damage and the likelihood of extrication. Three out of four drivers who required extrication occupied vehicles that sustained DVD.

Ejection

Ejection from the vehicle is another factor that was shown to be significantly associated with risk of TBI for drivers. Partial ejection was associated with an increase in risk nearly 11 times greater than those who were not ejected. Drivers who were totally ejected were 5 times more likely to experience TBI. Ejection is a rare event, occurring in 920 cases in the study population (0.58%). However, the likelihood of being ejected is greatly increased when seat belts are not worn – 7.6 times for partial ejection and 14.4 times for complete ejection (Table 9).

Table 9. Frequency of ejection from vehicle by seat belt use for crash-involved drivers in Kentucky, 1997

Ejection	**Unbelted**	**Belted**	**Total**
None	15,006	144,438	159,444
Partial	330	402	732
Complete	111	77	188
Total	**15,447**	**144,917**	**160,364**

Data source: Kentucky linked crash-TBI data, 1997

Other risk factors

Rural crash location, posted speed limit of 55 mph, DUI, and ages 45 and greater were also found to be associated with increased risk of TBI, independent of disabling vehicle damage, extrication from the vehicle, and ejection from the vehicle. Crash location and posted speed limit have been discusses already.

Driving under the influence of drugs and/or alcohol

DUI prevention programs exist that are specifically targeted at teenager drivers, and rightly so. But that age group actually has the least problem with MV-TBI related to DUI among all drivers under 50 years of age. 18.8% of all motor vehicle-related TBI among 16-19 year olds drivers involved suspicion of DUI, compared to 38.1% of 20-24 year olds, 40% of 35-39 year olds, and 44.8% of 40-44 year olds (Table 10). Programs aimed at reducing MV-TBI related to DUI should include these age groups.

Table 10. Suspected DUI by age group among crash-involved drivers in Kentucky who experienced a TBI

Age group	Percent in age group suspected DUI	Percent of all suspected DUI
16-19	18.8	13.9
20-24	38.1	20.9
25-29	27.7	11.3
30-34	29.1	13.9
35-39	40.0	15.7
40-44	44.8	11.3
45-49	21.7	4.4
50-54	9.4	2.6
55-59	9.1	1.7
60-64	12.5	1.7
65-69	15.4	1.7
70-74	0.0	0.0
75-79	8.3	0.9
80-84	0.0	0.0
85+	0.0	0.0
Total	**24.6**	**100.0**

Data source: Kentucky linked crash-TBI data, 1997

Older drivers

The risk of TBI was shown to increase with age. Drivers aged 65 years and older were nearly 1.8 times more likely to experience TBI than were drivers aged 25-44. The increased crash risks for drivers aged 65 and over have been well documented. Per mile driven, this group has more fatal crashes than any other age group except teenagers. Their crash rate per mile driven is three times that for drivers 30-64. Little scientific data are available on the effects of aging, chronic medical conditions, and prescription drugs on driving skills[8]. The rising percentage of older drivers in the U.S. makes this an important public health and highway safety issue.

Drivers aged 45-64 years were 1.5 times more likely to experience TBI when compared to drivers aged 25-44 years. This finding was unanticipated and requires further investigation.

Protective factors

Two factors studied were shown to be protective. Reported seat belt use by drivers significantly decreased the risk of TBI by 70% compared to those with no reported seat belt use. Also, drivers of crashes with one passenger and 2-3 passengers were 30% and 35%, respectively, less likely to experience TBI than those drivers who were alone at time of crash.

Seat belts

The protective effect of seat belt use has been widely reported in the crash literature. Statewide observational studies conducted over the past several years by the Kentucky Transportation Center have placed the usage rate between 55% and 60%[9]. Kentucky's crash data are unreliable for determining overall restraint use due to considerable reporting bias in non-injury crashes. However, when only crashes involving fatal or incapacitating injuries are considered, 62% of drivers in the study population were reported as belted (Table 11), a number which agrees with the observational studies. Drivers aged 16-29 had the lowest rates, at 55%-56%. For ages 30 and greater, two-thirds of drivers in fatal or incapacitating crashes were reported as belted, a significant improvement. Still, there is considerable room for increases in belt use in all age groups.

Table 11. Reported seat belt use among crash-involved drivers in Kentucky who received fatal or incapacitating injuries

Age	Number of drivers having fatal or incapacitating injury	Number of drivers belted	Percent of drivers belted
16-19	645	358	55.5
20-24	605	337	55.7
25-29	511	288	56.4
30-34	461	304	65.9
35-39	477	285	59.8
40-44	363	246	67.8
45-49	286	193	67.5
50-54	210	146	69.5
55-59	165	114	69.1
60-64	114	86	75.4
65-69	134	93	69.4
70-74	110	86	78.2
75-79	111	80	72.1
80-84	47	34	72.3
85+	23	11	47.8
Total	**4,262**	**2,661**	**62.4**

Data source: Kentucky linked crash-TBI data, 1997

Number of occupants

It is well known that the crash risk for teenage drivers increases when other teenagers are present in the vehicle[10]. Nonetheless, this study found that the risk of TBI for drivers is *decreased* when 1, 2 or 3 passengers are present in the vehicle. Further study is needed to explain this effect.

Conclusion

For reasons discussed in the “Limitations” section under “Data completeness,” we have been advised by NHTSA to refrain from making recommendations about resource allocation based on the results of this study. We have been further advised to conduct a follow-up study using a multiple imputation (MI) strategy to address the limitations of missing risk factor data and unlinked MV-TBI cases, and using multiple years of crash and TBI data. With these concerns in mind, we make the following observations.

Disabling vehicle damage, extrication, and ejections were shown to be associated with significantly increased risk of TBI. Drivers with reported seat belt use showed a significant decreased risk. This study suggests that crash severity, measured by the proxies of the risk factors mentioned above, is the strongest determinant of TBI in drivers of passenger vehicle crashes. Interventions that would reduce the amount of damage to crash-involved vehicles should be explored.

One in four crash-involved vehicles driven by a teenage driver (age 16-19) in 1997 sustained disabling vehicle damage, which places this group at high risk for TBI. Kentucky’s partial graduated driver licensing (GDL) law provides a mechanism for addressing this problem. The factors identified in this study may suggest areas where the law can be improved. For example more severe restrictions may be appropriate on driving on certain types of roadways, and particularly in rural areas where severe crash rates are higher.

Statewide observational studies conducted by the Kentucky Transportation Center (KTC) indicate that forty percent of drivers do not wear seat belts, which places them at nearly 3 times greater risk of TBI than belted drivers. Interventions that increase seat belt use will decrease the incidence of TBI in drivers.

DUI increases the risk of TBI, and this study suggests that interventions are needed that target drivers aged 20-24 and 35-44, in addition to existing programs that address teenage drivers.

Another option for decreasing the occurrence of severe crashes is to modify dangerous sections of road. The KTC report, “Safety Impacts of Rural Road Construction” has proved the safety benefits of engineering modifications to 2-lane rural roads. In addition, this CODES study suggests that engineering measures that reduce the occurrence of collisions with fixed objects, such as trees, light poles, and telephone poles, will decrease the incidence of TBI in drivers.

Limitations

Data completeness

One limitation of this study is the failure to account for all cases of MV-TBI, a situation caused by several factors. The first is missing data for risk factor variables on hospital discharge and trauma registry records, death certificates, and crash reports. The second is incomplete TBI case identification resulting from drivers who crashed in Kentucky being hospitalized out of state, and from unavailability of data for persons who were treated and released from hospital emergency departments. Finally, errors are inherent in the data linkage process. Some pairs that are true matches will fail to link (false negative matches), and some pairs that are not true matches will link erroneously (false positive matches). (The Automatch linkage software does allow the user to specify an acceptable rate of false positive matches. The rate of false negative matches can be estimated by determining the percentage of cases that should have linked but did not.)

This combination of factors resulted in the omission of a significant percentage of true MV-TBI cases from the study, which limits the confidence with which we can apply the findings to the targeting of injury prevention resources for MV-TBI. In cooperation with the CODES states, NHTSA is currently developing a methodology that uses multiple imputation to address the problem of missing cases due to (1) failure to link true cases, and (2) dropping of cases due to missing risk factor data on linked cases. The design of this study, and its usefulness for resource allocation, would be significantly improved by applying the MI methodology, as well as by using several years of data rather than a single year.

Data reporting biases

Reporting biases and misclassification of risk factors may exist which leads to a misrepresentation of risk. For example, over 90% of crash-involved persons were reported as wearing a seat belt, a utilization rate which greatly exceeds the 55%-60% reported in recent statewide observational studies.

Exposure to risk factors

Finally, the case-control methodology used in this study may not be the best indication of true exposure to risk factors. It completely ignores persons in vehicles that were *not* involved in crashes. A methodology that measures, for example, exposures per millions of vehicle miles traveled might yield more accurate assessment of risk factors.

References

1. Centers for Disease Control, National Center for Injury Prevention and Control. *Epidemiology of traumatic brain injury in the United States.* http://www.cdc.gov/ncipc/dacrrdp/tbi.htm

2. The National Institutes of Health Consensus Development Panel on Rehabilitation of Persons With Traumatic Brain Injury. Rehabilitation of persons with traumatic brain injury. *JAMA*. 1999; 282:974-981.

3. Thurman D, Guerrero J. Trends in hospitalization associated with traumatic brain injury. *Journal of the American Medical Association*. 1999; 282: 954-957.

4. Traumatic brain injury – Colorado, Missouri, Oklahoma, and Utah, 1990-1993. *MMWR.* January 10, 1997; 46(01): 8-11.

5. Goldstein LA, Spurlock CW, Kidd PS. Economic costs of motor vehicle crashes involving teenaged drivers in Kentucky. *Injury Prevention*. 1997; 3:200-206..

6. Gabella B, Hoffman RE, Marine WW, Stallones L. Urban and rural traumatic brain injuries in Colorado. *Annals of Epidemiology*. 1997; 7:207-212.

7. Agent K, Pigman J. S*afety Impacts of Rural Road Construction.* Kentucky Transportation Center, University of Kentucky College of Engineering, Lexington, Ky.

8. Centers for Disease Control, National Center for Injury Prevention and Control. *Fact book for the year 2000 – motor vehicle-related injuries.* http://www.cdc.gov/ncipc/pub-res/FactBook/fkmve.htm

9. Agent K. *1999 Safety Belt Usage Survey in Kentucky*. Kentucky Transportation Center, University of Kentucky College of Engineering, Lexington, Ky.

10. Cvijanovich N, Cook LJ, Mann NC, Dean MJ. A population-based study of crashes involving 16- and 17-year-old drivers: the potential benefits of graduated driver licensing restrictions. *Pediatrics*. 1996; 98:987-990.

Appendix A.

Passenger vehicle body type codes

The following codes were used to select passenger vehicles for this study.

1. “2D” Sedan 2-door
2. “3D” Sedan 3-door
3. “4D” Sedan 4-door
4. “5D” Sedan 5-door
5. “AM” Ambulance
6. “CB” Cab
7. ”CV” Convertible
8. ”HC” House car
9. ”HR” Hearse
10. ”JE” Code value unknown
11. ”LM” Limousine
12. “PK” Pickup
13. “PM” Pickup (camper mounted on bed)
14. “RW” Ranch wagon
15. “SD” Sedan
16. “SW” Station wagon
17. “TK” Truck
18. “TM” Truck mount camper
19. “UT” Utility vehicle
20. “VN” Van
21. “VT” Vanette