Association of Helmet Use with Death in Motorcycle Crashes: A Matched-Pair Cohort Study

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The association of helmet use with death in a motorcycle crash can be estimated using matched-pair cohort methods. By estimating effects among naturally matched pairs on the same motorcycle, one can account for potential confounding by motorcycle characteristics, crash characteristics, and other factors that may influence the outcome. The authors used Fatality Analysis Reporting System data, from 1980 through 1998, for motorcycles that crashed with two riders and either the driver or the passenger, or both, died. For their main analysis, the authors estimated the relative risk of death using conditional Poisson regression. The relative risk of death, accounting for the matching on motorcycle and adjusted for age, sex, and seat position, for a helmeted rider compared with an unhelmeted rider was 0.61 (95% confidence interval: 0.54, 0.70). The authors suggest that conditional Poisson regression is useful for the analysis of traffic crash data, where occupants are naturally matched in a vehicle and where crash-related confounders may be difficult or impossible to measure. Am J Epidemiol 2002;156:483–7.

Abbreviation: CI, confidence interval.

About half of all fatalities to motorcyclists from 1979 through 1986 were attributed to head injury (1). In 1998, 2,284 motorcyclists were killed, and an additional 49,000 were injured in traffic crashes in the United States (2). Per mile traveled in 1997, motorcyclists were about 14 times more likely to die compared with car occupants (2).

A few studies have estimated the relative risk of death among those helmeted compared with those not helmeted; estimates range from 0.54 to 0.72 (3–5). The risk ratio for death, for those wearing a helmet compared with those not wearing one, can be estimated using matched-pair cohort methods (5–10). The study population is motorcycle driver-passenger pairs who crashed on the same motorcycle. By estimating effects among these naturally matched pairs, we can account for potential confounding by motorcycle make and model and by crash characteristics such as speed, type of crash, response time of ambulance personnel, and other factors that may influence the outcome. Within these pairs there may still be differences between drivers and passengers with regard to individual-level factors, such as age, sex, and seat position. Assuming that we can measure the potential confounding factors not accounted for by matching, we can usually control for them by using stratified or regression methods (10). We undertook to estimate the association between helmet use and death using several analytic methods for matched-pair cohort data.

MATERIALS AND METHODS

Study sample

The National Highway Traffic Safety Administration operates the Fatality Analysis Reporting System, which collects information regarding all US crashes on public roads that result in a fatality within 30 days (2). Each case has more than 100 coded data elements that characterize the crash, the vehicles, and the people involved. Although the data are detailed in terms of crash-related factors such as speed, most

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harmful event, road conditions, and individual-level factors such as age, sex, and alcohol use, they lack detail regarding the anatomic location of injury or physiologic cause of death.

We selected from these data information regarding motorcycles that crashed with two riders and either the driver or the passenger, or both, died; thus, we selected motorcycles with a dead driver and dead passenger, a dead driver and living passenger, and a living driver and dead passenger. Motorcycle crashes in which both the driver and the passenger survived are not usually in Fatality Analysis Reporting System data; however, these pairs are not needed for a matched-pair cohort relative risk estimate (5–10). Because few drivers were children, we required that both riders were aged 16 years or older.

A total of 11,477 pairs were selected from crashes during 1980–1998. We eliminated 1,853 motorcycles because information regarding helmet use was missing for at least one rider, and we dropped 402 motorcycles with missing data regarding occupant position, age, or sex, leaving 9,222 pairs for the analysis. Riders with missing helmet data were similar to other riders with regard to the percentage that was male (72.6 percent compared with 70.7 percent) and the mean age (27.0 years compared with 27.2 years). Among the 804 riders omitted because of missing information about age, sex, or seat position, 40.7 percent were wearing a helmet compared with 39.1 percent of the 18,444 riders included in the sample used for analysis.

Exposure variables

The exposure of interest was helmet use. Variables that we treated as potential confounders were occupant sex, seat position (driver or passenger), and age in years. We examined several transformations of age, including age and age squared as continuous variables; these transformations made little difference to the final estimates, and we ultimately categorized age as 16–20, 21–25, 26–40, and 41 years or older.

The existence of a law requiring helmet use might induce some crash survivors to claim to have been wearing a helmet when they were not; this would exaggerate any protective association of helmets with death. To test this possibility, we added to the data information regarding whether or not each rider was required by state law to wear a helmet, according to occupant riding position, age, and date of the crash (11).

Outcome

The outcome in this study was death within 30 days of the crash. We ignored the time to death, simply treating the outcome as binary.

Statistical methods

For our main analysis, we estimated the relative risk of death using conditional Poisson regression, a method suitable for generating relative risk estimates from matched-pair cohort data (10, 12). To test statistical interaction terms in the regression models, we used the likelihood ratio test (13). For purposes of comparison, we also generated some relative risk estimates with three other methods: 1) a Mantel-Haenszel stratified method for matched-pair cohort data (7, 9, 10); 2) the double-pair method as described by Evans (8), with a modified variance estimator (10); and 3) conditional logistic regression (14). Confidence intervals for the overall (driver and passenger) relative risk estimates from the double-pair method were calculated using bias-corrected bootstrap methods (15).

RESULTS

The final study sample consisted of 9,222 driver-passenger pairs. Study riders were most often male (70.7 percent) and had a mean age of 27.2 years and median age of 24 years. Helmeted riders were more often female (31.2 percent) and more often the driver (51.8 percent) compared with unhelmeted riders (28.1 and 48.9 percent, respectively; table 1). The mean age of helmeted riders was 28.8 years and that for unhelmeted riders was 26.2 years. Among unhelmeted riders, 60.1 percent died compared with 58.7 percent among helmeted riders.

Accounting for the matching on motorcycle, the relative risk of death for a helmeted rider compared with an unhelmeted rider was 0.65 (95 percent confidence interval (CI): 0.57, 0.74), using conditional Poisson regression. There was little confounding by age or sex, as the estimate adjusted for these variables was the same to two decimals. There was mild confounding by seat position (driver or passenger). The relative risk adjusted for age, sex, and seat position was 0.61 (95 percent CI: 0.54, 0.70) (table 2).

We examined the possibility that crash characteristics might modify the effects of seat position, and this in turn might change the estimated relative risk of death according to helmet use. The following characteristics were examined: vehicle role in the crash (noncollision, striking, struck, both), manner of collision (noncollision, rear end, head on, rear to rear, angle, sideswipe in the same direction, sideswipe in the opposite direction), most harmful event (30 categories, such as collision with a train, struck a utility pole, and so on), pavement type (concrete, blacktop, and other), drinking by the driver, speed limit, estimated speed and speed squared, and angle of impact (categorized as frontal (11–1 o’clock), side (2–4 o’clock and 8–10 o’clock), and rear (5–7 o’clock)). For each of these characteristics, we introduced interaction terms between the seat position and the new variable. Although several of these interaction terms were statistically significant, including the interaction terms in the regression model had almost no effect on the relative risk estimates for helmet use and death.

All the crash characteristics examined as interaction terms in the previous paragraph were also examined as interaction terms with helmet use. We found that the relative risk of death associated with helmet use did not vary in a statistically significant manner ($p \geq 0.2$) with any of these crash characteristics, except for variation by whether or not the crash involved a collision ($p = 0.008$). For those crashes (88 percent of all crashes in our study) involving a collision with a vehicle or other object, the adjusted relative risk of death comparing a helmeted rider with one not helmeted was 0.65 (95 percent CI: 0.57, 0.75). In the 12 percent of crashes that involved no collision, in which the motorcycle skidded or
turned over, the adjusted relative risk estimate was 0.36 (95 percent CI: 0.24, 0.56).

There was evidence that the association between helmet use and death was modified by both seat position and sex of the rider; the \( p \) value for interaction terms was 0.004 for seat position and 0.009 for sex. However, seat position and sex were strongly related: 97.4 percent of women in these data were passengers. When both interaction terms were added to the model, neither was statistically significant: \( p = 0.2 \) for the seat position term and \( p = 0.5 \) for the sex term. Given that the evidence was stronger for modification of helmet effects by seat position, we added that interaction term only and estimated that, for helmeted compared with unhelmeted drivers, the adjusted relative risk of death was 0.65 (95 percent CI: 0.57, 0.74), while for passengers it was 0.58 (95 percent CI: 0.50, 0.66). There was little evidence that age modified the effects of helmets (\( p = 0.1 \)).

When a state law required that a rider of a given age or seat position wear a helmet, 72 percent of the riders in our sample wore a helmet; when there was no legal requirement to wear a helmet, 15 percent wore one. The adjusted relative risk of death for helmeted compared with unhelmeted riders in state time periods with a helmet law was 0.68 (95 percent CI: 0.57, 0.82). When wearing was not required, the estimate was 0.56 (95 percent CI: 0.48, 0.66). A test that estimated whether helmet effects varied according to the presence of a helmet law was not statistically significant (\( p = 0.1 \)).

Using the double-pair method, the estimated relative risk of death comparing helmeted drivers with unhelmeted drivers was 0.66 (95 percent CI: 0.59, 0.74). For passengers, the relative risk was 0.60 (95 percent CI: 0.54, 0.67). The average relative risk of death comparing all helmeted riders with unhelmeted riders was 0.63 (95 percent CI: 0.56, 0.70). With the Mantel-Haenszel method, the estimated relative risk of death comparing helmeted riders with unhelmeted riders was 0.65 (95 percent CI: 0.59, 0.73). Using conditional logistic regression, we found the relative odds of death, adjusted for age, sex, and seat position, to be 0.49 (95 percent CI: 0.42, 0.57).

**DISCUSSION**

In this analysis, the relative risk of death among helmeted riders, compared with unhelmeted riders, was estimated to be 0.61, controlling for motorcycle and crash-related factors, as well as age, sex, and seat position. There was some evidence that this association was stronger among passengers, compared with drivers, but the difference was not great.

This was a study of driver-passenger pairs who crashed. If helmet effectiveness varied by some characteristic of riders or crashes, and if drivers in crashes without a passenger differed in this characteristic compared with riders who were in pairs, then our estimates might not apply to motorcycle drivers who crashed without a passenger. We found, however, that there was little evidence that helmet effects varied by the age or sex of the rider. The relative risk estimates did differ somewhat by whether or not the motorcycle collided with an object. However, the proportion of crashes involving a collision was 88 percent for the crashes in our data and 90 percent for the crashes during 1980–1998 in which there was a driver only and that driver died. Thus, our average estimate of helmet effects from crashes with two riders may apply to crashes with a driver only. The relative risk estimates did differ somewhat by seat position. Our estimate that the risk of death was reduced by 35 percent for a helmeted driver compared with an unhelmeted driver may be a reasonable estimate of helmet effectiveness for drivers who crash without a passenger.

Our overall estimate of the relative risk of death, 0.61, was similar to estimates that we obtained by two other methods.
that can generate relative risk estimates for matched-pair data. The Mantel-Haenszel method produced an estimate of 0.65, and the double-pair method estimate was 0.63 (8–10). Conditional logistic regression, however, produced an odds ratio, 0.49, that was substantially different from the relative risk estimate. The odds ratio will be farther from 1.0 than the risk ratio if the study outcome is common in a noteworthy portion of the data (16). This problem is apparent in the study data; in 19.1 percent of the crashes, both riders died.

An important limitation of any study of motorcycle helmets is that estimates may be biased if helmet use is inaccurately reported. In particular, some riders who survived a crash might falsely claim helmet use in the presence of a law requiring helmet use; this would make helmets appear to be more effective in the presence of a law. We found no evidence of such a bias; the estimate of association was actually weaker in the presence of motorcycle helmet laws. Another limitation is that the data contained no information about helmet characteristics, and therefore we could not determine whether any effects of helmets varied by helmet weight or helmet type.

Several studies have provided some information about the association between helmet use and head injury (17–20). A few studies have examined death as the outcome. Bachulis et al. (3) studied injured motorcyclists admitted to a single hospital in Oregon during 1983 through part of 1987. Among 235 unhelmeted riders, 23 died, compared with seven deaths among 132 helmeted riders (crude relative risk = 0.54, 95 percent CI: 0.23, 1.23). This study omitted those who died at the scene and those who were not hospitalized, and it failed to account for any potential confounders.

Evans and Frick (4) analyzed Fatality Analysis Reporting System data for 1975 through 1986 for rider pairs on the same motorcycle. They applied the double-pair method, a stratified matched-pair cohort method, to pairs that did not differ by more than 3 years of age; only pairs with a male driver were used (8, 10). They reported that helmets reduced the risk of death by 28 percent (standard deviation, 8 percent). The difference between their estimate and our estimate of 39 percent appears to be due partly to their failure to account for confounding by seat position and partly to the more restricted sample in their study. When we limited our analysis to male drivers only and to the time prior to 1987, the average mortality reduction estimate was 31 percent, accounting for matching. When we adjusted further for age and seat position, the estimate was 37 percent. Wilson (21) also applied the double-pair method to crash data from 1982 through 1987 and estimated a 29 percent decrease in mortality associated with helmet wearing.

Greenland (5) reanalyzed data from the study of Evans and Frick (4), using an estimating equation method for risk ratios. He estimated that the relative risk of death associated with helmet use was 0.71 (95 percent CI: 0.61, 0.84). When we applied conditional Poisson regression to these same data, our estimate was 0.71 (95 percent CI: 0.59, 0.86).

Conditional Poisson regression has not been applied often to matched-pair cohort data (22, 23). We suggest that this method may be especially helpful in the analysis of traffic crash data, where occupants are naturally matched in a vehicle, but crash- and vehicle-related confounders may be difficult or impossible to measure (10). If the association that we found between helmet use and death is causal, our results suggest that wearing a helmet in a crash can prevent about four of 10 deaths that would otherwise have occurred.

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