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Motorcycle helmet use and the risk of head, neck, and fatal injury: Revisiting the Hurt Study

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ABSTRACT

Most studies find strong evidence that motorcycle helmets protect against injury, but a small number of controversial studies have reported a positive association between helmet use and neck injury. The most commonly cited paper is that of Goldstein (1986). Goldstein obtained and reanalyzed data from the Hurt Study, a prospective, on-scene investigation of 900 motorcycle collisions in the city of Los Angeles. The Goldstein results have been adopted by the anti-helmet community to justify resistance to compulsory motorcycle helmet use on the grounds that helmets may cause neck injuries due to their mass. In the current study, we replicated Goldstein's models to understand how he obtained his unexpected results, and we then applied modern statistical methods to estimate the association of motorcycle helmet use with head injury, fatal injury, and neck injury among collision-involved motorcyclists. We found Goldstein's analysis to be critically flawed due to improper data imputation, modeling of extremely sparse data, and misinterpretation of model coefficients. Our new analysis showed that motorcycle helmets were associated with markedly lower risk of head injury (RR 0.40, 95% CI 0.31–0.52) and fatal injury (RR 0.44, 95% CI 0.26–0.74) and with moderately lower but statistically significant risk of neck injury (RR 0.63, 95% CI 0.40–0.99), after controlling for multiple potential confounders.

1. Introduction

Most studies find strong evidence that motorcycle helmets protect against injuries during traffic collisions but some studies have claimed a positive association between helmet use and neck injury. Numerous studies have looked at the possible role of motorcycle helmets in the causation of neck injury among motorcyclists during traffic collisions. Liu et al. (2004) conducted a Cochrane review of the effects of motorcycle helmet on fatality, head injury, and neck injury. They identified 16 studies that used neck injury as an outcome and reported that the data could not support any conclusion about the possible association between helmet use and the occurrence of neck injury. They estimated a pooled odds ratio of 0.85 (95% CI 0.66–1.09, p 0.69) for neck injuries.

A small number of studies have reported a positive association between motorcycle helmet use and neck injury. The most commonly cited paper is that of Goldstein (1986). Goldstein obtained the final data sets from the Hurt Study, a prospective, on-scene, in-depth investigation and reconstruction of 900 motorcycle collisions in the city of Los Angeles (Hurt et al., 1981a). Hurt's team of motorcyclist-investigators conducted their independent crash scene evidence collection during police investigation immediately after a collision (627 cases) or within 24 h (283 cases). They interviewed riders and other motorists, photographed vehicles and skids, and obtained 261 of 355 helmets riders wore when they crashed. They later compiled this evidence to identify crash and injury causation.

Goldstein applied probit and Tobit models to the Hurt Study data and drew three primary conclusions: (1) helmets provided protection against head injury, (2) helmets had no influence on fatal injury, and (3) helmets caused neck injuries at impact speeds of 13 MPH or greater. Several authors have criticized Goldstein's methods (Bedi, 1987; Weiss, 1992; Lawrence et al., 2003) and his results are incompatible with a majority of the published research. Hurt Study researchers have questioned the findings because Goldstein's analysis used an independent variable called "normal component of impact velocity" to the helmet that they

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recorded for 5% of helmeted motorcycle riders. The Hurt Study investigators found that it was usually impossible to accurately estimate the normal component of impact velocity value and discontinued its collection early in the study, thus the value was missing for a large majority of helmeted riders. Because this variable appeared in the Helmet section of the Hurt Study data forms, it was recorded as "not applicable" for all of the unhelmeted riders. This variable is almost always much less than the motorcycle crash speed. For example, during a crash, if the helmet hits the horizontal pavement at a vertical, downward speed of 9½ mph (the equivalent of an uninterrupted 3-foot drop), then 9½ mph is the normal component of impact velocity to the helmet, whether the motorcycle rider was traveling horizontally, parallel to the pavement at 1, 10 or 100 MPH just before the crash.

Because Goldstein's unexpected results are so widely known (among motorcyclists and, particularly, among individuals and groups involved in anti-helmet activities), we aimed to (1) obtain and analyze the same data from the Hurt Study that Goldstein used, (2) replicate the analysis performed by Goldstein, and (3) reanalyze the data using modern statistical models not available at the time of Goldstein's analysis.

2. Methods and procedures

The Hurt Study involved the detailed, on-scene investigation of motorcycle collisions in Los Angeles, California that occurred between January 1976 and December 1977 (Hurt et al., 1981a). Hurt's investigators collected data through direct observation, photography and measurement of physical evidence, medical documents, personal interviews with motorcyclists, other vehicle drivers and victims, and witnesses. Data were also collected at hospital emergency departments, coroner offices, and at tow yards. They collected 261 of 355 helmets worn and kept them for examination and disassembly to identify and record all damage. In order to encode head-neck injuries in much greater detail than existing coding systems allowed, the Hurt Study investigators created a head-neck injury coding system modeled on the Occupant Injury Classification (OIC) (Marsh, 1973). The OIC was an alphabetic injury coding system that predated and set the pattern for the all-numeric Abbreviated Injury Scale (AIS). As with the current AIS, the system encoded each injury by location (body region, side, and aspect), system or organ involved, and type of injury (abrasion, fracture, laceration, etc). Injury severity was coded by consulting resident pathologists using the 1976 version of the AIS (American Association for Automotive Medicine, 1976). Ouellet et al. (1984) published a detailed description of the head-neck injury coding system used in the Hurt Study. Each Hurt Study case involved answering roughly 400–500 questions about the crash. Many were simple questions such as the day of the week, motorcycle manufacturer, or rider gender. Others were much more complex, such as vehicle speeds, crash causes, and contributing factors. When all data had been collected, each case was reconstructed to determine elements such as crash speed, collision avoidance actions, accident cause, and injury-causing contacts.

Hurt Study data sets, data outputs, and documentation were obtained directly from the Hurt Study investigators. The final data sets from the study were obtained in SPSS format or as ASCII files. We had the advantage of using the Hurt Study data forms (Hurt et al., 1981b) and guidance from Hurt study authors (David R. Thom, James V. Ouellet, and Terry Smith) to assure that data within the original flat files were properly organized and understood. Data were converted to Stata format, and separate files were created for 900 motorcyclists, 861 head, neck, or facial injuries, and 3020 below-the-neck injuries.

2.1. Replication of Goldstein analysis

To identify the subset of 644 riders used by Goldstein, we obtained a data output provided by Goldstein to the Hurt Study investigators after the completion of his analysis. Goldstein's 1986 publication provided details on how variables were prepared and we attempted to duplicate all of his data procedures. We recreated the head injury severity measure, as Goldstein did, using the sum of the squared AIS scores for all head injuries; we also recreated the neck injury severity measure using the sum of the squared AIS scores for all neck injuries. Consistent with Goldstein, we fitted a probit model using a fatality indicator as the outcome, and we fitted a Tobit model using each of the head and neck injury severity measures as the outcome. The probit and Tobit models were fitted using Stata's 'probit' and 'tobit' procedures, respectively. Goldstein used two methods for calculation of kinetic energy. We used his first method in our replication models because Goldstein indicated that the first method improved the fit of his models to the data. Goldstein also included single year of age, blood alcohol concentration, evasive action taken by rider (yes/no), street motorcycling experience (months), and helmet by rider weight interaction. We included these variables in our replication models.

2.2. New analysis

The objective of our new analysis was to estimate the associations between helmet use and the occurrence of three outcomes among the 900 collision-involved motorcyclists in the Hurt Study database. The outcomes were neck injury, head injury, and fatal injury. We developed directed acyclic causal graphs to identify potential confounders of the helmet-injury associations (Greenland et al., 1999). We identified rider age, rider sex, rider alcohol use, motorcycle type, motorcycle collision speed, collision type, number of involved vehicles, type of object struck, rider evasive action pre-collision, distance between rider point of rest and collision point of impact, and below-the-neck injury severity as potential confounders. We defined neck injuries as injuries coded as 'cervical vertebra 1–7 plus adjacent superior joints,' 'cervical-general,' or 'throat.' The most severe injury in each of the head, neck, and below-the-neck regions was calculated for each rider. Due to the small number of AIS >1 neck injuries ($n = 16$), we used the presence of a neck injury of any severity (AIS >0) as the outcome.

Bivariate associations were examined using Pearson Chi-sq or Fischer's exact tests. We estimated crude risk ratios (RR) and adjusted risk ratios (aRR) using log-binomial regression (Barros and Hirakata, 2003; McNutt et al., 2003; Vittinghoff et al., 2012). Potential confounders were included in the model if they were significant predictors of neck injury at $p < 0.15$ or if their removal from the model resulted in a change of 10% or greater in the helmet use coefficient. Age was modeled as continuous, quadratic, and categorical. The other model coefficients were nearly identical across the three approaches, and age categories were used for the result tables. Motorcycle speed was also modeled as continuous, quadratic, and continuous. The models with continuous motorcycle speed were as informative as the others, so these models were used. All models were fitted to data on 882 riders (98%) for whom age, sex, motorcycle speed, and helmet use status were known. All data management and analysis was done with Stata 13 (StataCorp, 2014).

3. Results

The Hurt Study collected data on 900 motorcycle operators involved in traffic collisions (Table 1). Forty percent of riders were helmeted at the time of collision. The sample is dominated by young male riders; 85% were aged 34 or younger, and 96% were male.