Costs of Injuries Resulting from Motorcycle Crashes:
A Literature Review

Appendix B

Critical Reviews of Other Publications

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Cooter, R.D., David, D.J., McLean, A.J., & Simpson, D.A. (1988). Helmet-induced skull base fracture in motorcyclist. *The Lancet, 8577,* 84-85.

Abstract

Purpose & Study Population. Case study of a 19-year-old male motorcyclist who fell from his motorcycle at an intersection, slid along the road, and struck the front of his helmet on the edge of a curb, resulting in unconsciousness, blood flow from the ear canals, and death, despite the apparent absence of facial damage.

Data & Methods. Radiology (CT scan) of both head and helmet, plus necropsy of victim, focusing on head.

Results & Conclusion. Observations suggested that the face bar of a full-face helmet may transmit an impacting force to the skull base via the chin strap and the mandibular rami and condyles, bypassing the energy-absorbing facial bones. If this mechanism is confirmed, the structural properties of these face bars will need to be reassessed.

Strengths

Both the victim and the helmet were examined thoroughly using CT scans and other methods.

The authors make appropriately modest recommendations. They suggest only a reassessment of the structural properties of the face bar; they do *not* question the overall value of helmets in general or of full-face helmets in particular.

Weaknesses

The medical conclusion is somewhat speculative - as the authors implicitly acknowledge when they suggest the need for confirmation of their proposed injury mechanism. We, as economists, are not qualified to evaluate the medical theory, but several researchers who have looked into the hypothesis of injury from full-face helmets have discredited the theory. (See, for example: Thom, D.R. & Hurt, H.H. (1993). Basilar Skull Fractures in

Fatal Motorcycle Crashes. *37th Annual Proceedings, AAAM*, 61-76. An evaluation of Cooter et al. appears on page 65.)

Even if the proposed injury mechanism is correct for this one case, it is difficult to draw more general inferences from a single case, especially in light of the unusual way the injury occurred. Perhaps the crash was unsurvivable, and in the absence of the face bar, the victim would have may died when his chin or throat hit the curb. Moreover, even if the face bars of full-face helmets were responsible for occasional deaths, it is possible that they might save even more lives. The present article gives no way to evaluate the aggregate impact of the face bar.

Goldstein, J.P. (1986). The effect of motorcycle helmet use on the probability of fatality and the severity of head and neck injuries: A latent variable framework. *Evaluation Review 10*(3), 355-375.

Abstract

Purpose. The purpose of this paper is to develop, estimate, and statistically test causal models for 1) the probability of a fatality; 2) the severity of head injuries; and 3) the severity of neck injuries, conditional on the occurrence of a motorcycle accident. Particular attention is paid to the effectiveness of helmets in each instance.

Study Population & Data. The data analyzed in this study, provided by NHTSA, were originally collected from on-scene in-depth investigations of 900 motorcycle crashes, in the Los Angeles area, supervised by Hurt et al. (1981). Each crash was completely reconstructed, and 1,045 data elements covering accident characteristics, environmental factors, vehicle factors, rider, passenger, and driver characteristics, and human factors including both injuries and protection system effectiveness were recorded. At the time of this study, these data were recognized as the most accurate and detailed available on motorcycle accidents.

Methods. The study employs regression analysis to estimate a causal model that isolates the effectiveness of helmets and other determinants of death and injury severity resulting from motorcycle crashes. The advantage of a causal model lies in its ability to estimate the separate effects of several simultaneous and interrelated causes of motorcycle injuries. If, for example, helmeted riders are more risk-averse and thus 1) have lower crash speeds, and 2) are less likely to combine alcohol consumption and driving, a causal model that considers crash speed, helmet use, alcohol use, and other pertinent variables can isolate the separate contribution of each determinant of injury severity or probability of death. The causal model considers three broad categories of factors: 1) physical factors (e.g., kinetic energy, helmet use); 2) physiological factors (e.g., operator's age, blood alcohol level); and 3) human factors and operator characteristics (e.g., rider experience, training, operator's past accident and violation histories).

Results. Helmets were not found to have a statistically significant effect on the probability of fatality given that a motorcycle crash had occurred. The major determinants of fatality were found to be the rider's crash speed and blood alcohol level. For the average rider involved in the average accident, it was found that the probability of death increased from 2.1 percent to 11.3 percent when the rider's blood alcohol level increased from 0.0 to 0.1 (from sober to legally intoxicated in most states). An increase in crash speed from 40 to 60 mph increased the probability of death from 7.1 percent to 36.3 percent.

Helmets were found to have a statistically significant effect in reducing head injury severity. However, it was also found that, past a critical impact velocity to the helmet (approximately 13 mph), helmet use has a statistically significant effect which increases the severity of neck injuries. This implies that a tradeoff between head and neck injuries confronts a potential helmet user. Further statistical tests showed that an individual who wears a helmet and experiences an impact velocity to the head greater than 13 mph may avoid either severe or minor head injuries and incur either severe or minor neck injuries; all permutations of the tradeoff are equally likely to occur.

Conclusions. If a major concern of policy makers is the prevention of fatalities, helmet legislation may not be effective in achieving that objective. If the overall cost to society of motorcycle crashes is the issue, then cost-benefit analysis that adequately consider the tradeoff between head and neck injuries must be conducted before the cost-effectiveness of helmets can be determined. Until the injury tradeoff issue is more carefully studied, it cannot be concluded that mandatory helmet use laws are an effective method to eradicate the death and injury of motorcycle crash victims. More effective policies might include: 1) the education of the general driving public; 2) the education of younger and more inexperienced motorcyclists; 3) stricter enforcement of drunk driving laws; 4) implementation of alcohol awareness programs; 5) stricter enforcement of speed limits; and 6) mandatory driver training and education programs which emphasize the proper execution of evasive action.

Strengths

Goldstein used a detailed dataset and used it to examine questions of serious policy interest.

Weaknesses

According to Hurt, whose data Goldstein uses, Goldstein got his physics wrong (the equation for relative impact velocity used an incorrect definition of impact angle) and, moreover, drew conclusions contrary to the effects found in simply tabulating the data. In the data, helmeted riders had much lower chances of serious head or neck injury.

There is also a major flaw in the statistical model. The model contains a cross-product (HI) of helmet use (H) and impact velocity (I), which takes a value of 0 for unhelmeted riders but a rising value with impact for helmeted riders. The model does not include impact velocity (I) as a separate variable. The cross-product variable is the key to Goldstein's results. Unfortunately, it is 0 for those who are injured seriously because they are unhelmeted, but increases for helmeted riders who are injured because the impact is higher. To make matters worse, when HI was missing Goldstein set it to the mean value, then used the observations in the regression. That procedure cannot possibly yield a more accurate model than omitting the missing cases. In other words, HI yields a confused, uninterpretable coefficient.

A third major problem with the model is that it trades off percentage changes in neck and head injuries, without noting that neck injuries occurred only one-tenth as often as head injuries. Related to this, Hurt says these data contained almost no serious neck injuries, throwing the whole model into question. A fourth major problem with the paper was that it threw out 28 percent of the observations, including 43 percent of the fatalities, because regression variables were missing, so the remaining cases did not represent the injury distribution accurately. Another fatal flaw was that the regression showed helmet weight did not affect injury probability. Goldstein somehow concluded that helmet mass did, ignoring the fact that experimental and simulation data show the two are linearly proportional in typical motorcycle crashes.

It appears that Goldstein incorrectly assumed that all injuries except AIS 6 were nonfatal. Some people die from complications of AIS 1 injuries, and injuries of AIS 3 and up have fairly high risks of death. If the analysis did not recode all deaths to fatal, it may have incorrectly treated dead people as survivors since their injuries were not AIS 6.

Simpson, D.A., Blumbergs, P.C., Cooter, R.D., Kilminster, M., McLean, A.J., & Scott, G. (1989). Pontomedullary tears and other gross brainstem injuries after vehicular accidents. *Journal of Trauma, 29*(11), 1519-1525.

Abstract

Purpose. Case study.

Study Population, Data, & Methods. In a series of 988 autopsied victims of road crashes in South Australia in 1983-1987, there were 36 (3.6 percent) cases of gross primary brainstem injury. Neuropathological reports, autopsy reports, and accident reports were reviewed. Helmets were examined when available (12 cases) and CT scanned when useful.

Results. The 36 cases fell into three groups. The first comprised 8 cases of pontomedullary tearing without other gross brain injury: in 7 of these, there were associated atlanto-occipital dislocations and/or high cervical fracture-dislocations. The usual cause appeared to be facial impact inducing acute hyperextension. Second, there were 17 cases of pontomedullary tearing associated with other brainstem lacerations and/or major damage elsewhere in the brain: in all, there were fractures of the skull base, typically transverse middle fossa fractures. Most of these injuries appeared to be due to facial impacts transmitting force to the anterior skull base, although hyperextension was also a factor in some. There was a third heterogeneous group of 11 cases with brainstem

lacerations in sites other than the pontomedullary junction: in some of these it appeared that the impacts had caused skull base fractures by inducing calvarial torsion.

Conclusion. In this series of fatal brainstem injuries, the proportion of motorcyclists (41.7 percent) was twice that found in the general series of fatal brain injuries due to road crashes (19 percent). The use of a helmet modifies the mechanisms of impact head injury; the overall benefits of helmet use are well established, but there is need for more research on helmet design.

Summary for the reader who is not a medical specialist

The *pons* and the *medulla* are two components of the brainstem. Injuries that involve high levels of force to the head, such as high-speed crashes, may result in a separation of the medulla from the pons. The result is almost always instant death.

These crash injuries are often accompanied by nonsurvivable injuries to other parts of the body. However, many such crashes, particularly among motorcyclists, do not involve other critical injuries (AISŽ5). Thus, the authors argue, ". . . that mitigation of the facial impacts which cause brainstem lacerations might save some lives." They infer the desirability of airbags in cars, because seatbelts alone do not reduce the incidence of severe head injuries. With respect to motorcyclists, they summarize their controversial argument from Cooter et al. (1988) to suggest that helmet design can contribute to the occurrence of brainstem injuries, and they conclude, "[W]e believe that the detailed study of specific injury patterns points to a need for further research into helmet design to ensure that the degree of protection conferred represents the best possible compromise between the many conflicting desiderata." (Note: The authors do not recommend any particular helmet changes or even assert that helmets should be changed from their current design; they simply say we do not know with certainty what the optimal helmet design looks like and call for more research on the subject.)

Given the size and detail of their dataset, the authors appear to slice it appropriately and take advantage of the case-level detail when useful.

It is difficult for a non-specialist to say any more about their data, methods, discussion, or conclusions. The discussion section is particularly difficult for a non-specialist to follow, but the entire paper is replete with hypothesized chains of anatomical causation, leading from impact on the head or neck to injury of the brainstem. There are places where it appears they might be arguing for chains of causation about which they anticipate disagreement, or which they suspect to be controversial.

United States General Accounting Office. (1991). *Highway Safety: Interim Report on Safety Belt and Motorcycle Helmet Effectiveness. Report to the Subcommittee on Water Resources, Transportation and Infrastructure,*

Committee on Environment and Public Works, U.S. Senate. **(GAO/RCED-91-158). Washington, DC: U.S. General Accounting Office.**

United States General Accounting Office. (1991). ***Highway Safety: Motorcycle Helmet Laws Save Lives and Reduce Costs to Society. Report to Congressional Requesters.*** **(GAO/RCED-91-170). Washington, DC: U.S. General Accounting Office.**

Abstract

Purpose. The Congress, as part of the federal highway safety program reauthorization, was considering bills that would use either penalties or incentives to encourage states to enact helmet laws. Representing the Committee on Environment and Public Works and the Subcommittee on Water Resources, Transportation and Infrastructure, two senators asked GAO to evaluate existing studies on motorcycle helmet laws and summarize their findings on (1) the effectiveness of helmets in preventing deaths and serious injuries, (2) the effect of helmet laws on helmet use and fatality rates, and (3) the costs that society incurs when motorcyclists who do not wear helmets are involved in crashes.

Study Population. Motorcycle registrations in the U.S. increased dramatically from less than 600,000 in 1960 to about 5.7 million in 1980 and later declined to about 4.4 million by 1989. The trend in motorcycle registrations reflected a similar trend in the male population aged 18 to 24, as well as changes in the prices of motorcycles and gasoline. Concurrently, the number of rider fatalities rose from about 800 in 1960 to over 5,000 in 1980 and then declined to about 3,200 in 1990. According to NHTSA, 55 percent of those who died in motorcycle fatalities in 1990 were not wearing helmets.

Data & Methods. GAO conducted a broad search for published and unpublished studies on motorcycle helmets and helmet laws and assembled a review panel with experience in research methodology to assist in evaluating studies and formulating conclusions. GAO’s conclusions were drawn from 46 studies that contained original data or original analysis and met minimum criteria for methodological soundness.

Results. Although the studies evaluated differed in the specific questions addressed and the methods used, they were consistent in pointing to a safety benefit from helmet use. The 11 studies that compared helmeted with nonhelmeted crash victims all found that helmeted riders had lower fatality rates. Rates ranged from 29 percent to 73 percent lower, depending on how researchers defined their study population. Eleven studies that addressed injury severity showed that surviving helmeted riders suffered fewer serious and critical injuries than nonhelmeted riders because they had a 46 percent to 85 percent lower incidence of severe to critical head injuries.

Nine studies reported that under universal helmet laws nearly all riders (92 percent to 100 percent) wore helmets, compared with roughly 50 percent (42-59 percent) under limited laws or no law. These data also indicated low helmet use among young riders in states with limited helmet laws. Twenty studies show that when universal helmet laws have

been in effect, fatality rates have generally been 20-40 percent lower than during periods before enactment or after repeal. If applied to the states not having universal helmet laws in 1990, and assuming that motorcyclists in those states were similar to their counterparts in states with universal laws, a 20-40 percent reduction would have meant a total of about 350 to 700 fewer deaths in those states in 1990.

The data on the cost of motorcycle crashes were less complete, but thirteen available studies did indicate that nonhelmeted riders were more extensive users of medical services and long-term care, and were more likely to lose earning capacity through disability. One study attempted to estimate the cost of lost years of productive life for 516 riders -- the number the authors calculated had died in 1980 because of helmet law repeals. Their estimate, updated to 1990 dollars, was nearly $250 million, or about $480,000 per death.

Several studies addressed the source of payment for hospital charges. They showed that roughly half of the nonhelmeted riders were covered by medical insurance, somewhat less than for helmeted riders. Public assistance programs were reported in two studies to have covered about one-fourth of the charges, while the remaining one-fourth were considered self-pay. The self-pay category may be misleading, however. One study which investigated this further found that public programs paid a much higher percentage and that riders and their families actually paid only about 1 percent of the total costs. Presumably, some of the cost was absorbed by the hospitals.

Conclusion. Because there is convincing evidence that helmets save lives and reduce society's burden of caring for injured riders, the Congress may wish to consider encouraging states to enact and retain universal helmet laws.

Strengths

This study surveys a number of publications that examined the impact of motorcycle helmet usage and legislation from different perspectives, using different data and methods. The consistency of findings between the various articles reinforces their conclusions regarding the effectiveness of helmet laws in encouraging helmet use and reducing fatality rates and injury costs.

The study acknowledged the questions of long-term costs and indirect costs, even though it gave only rough estimates of each.

Weaknesses

The presentation of findings on costs and payers was less detailed than of that on incidence.

Conclusion

This study provides good coverage of motorcycle helmet studies published before 1990. This makes it a good complement to the present project, which begins with 1990 publications.