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Fatality risk in motorcycle collisions with roadside objects in the United States

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ABSTRACT

Motorcycle crashes with roadside objects often involve more than one impact event: typically involving a collision with the ground and another object. The objective of this study was to determine the fatality risk in these roadside object collisions when compared with crashes only involving a collision with the ground. The roadside objects analyzed included guardrails, concrete barriers, signs, utility poles, and trees. The Fatality Analysis Reporting System (FARS) database was used in conjunction with the General Estimates System (GES) to analyze fatality risk for motorcycle crashes from 2004 to 2008. The analysis was based upon over 3600 fatal motorcycle crashes with roadside objects. Collisions with roadside objects were found to have a higher fatality risk than collisions with either the ground or another motor vehicle. Based on the most harmful event reported in the crash, motorcycle collisions with guardrail were 7 times more likely to be fatal than collisions with the ground, and collisions with trees were almost 15 times more likely to be fatal than collisions with the ground. Additionally, the roadside object was reported as the most harmful event in the majority of the crashes in fatal two-event crashes involving a roadside object and a collision with the ground, with the exception of collisions with signage. From these analyses it was concluded that collisions with fixed objects are more harmful to motorcyclists than collisions with the ground.

1. Introduction and background

The risk of fatal injury for motorcyclists greatly increases when motorcyclists depart the roadway and collide with roadside objects such as trees, poles, or traffic barriers (Oullet, 1982; Quddus et al., 2002; Quincy et al., 1988; Shankar and Mannering, 1996; Tung et al., 2008). The elevated risk of fatal injury in motorcycle–barrier collisions (NHTSA, 2008) has been a major motivating factor in the growing concerns over the crash compatibility of traffic barriers and motorcycles. The assessment of fatality risk is complicated by the fact that motorcycle crashes frequently involve multiple impacts. For example, in a motorcycle–guardrail crash in which the rider falls onto the pavement after losing control of the cycle, the motorcycle suffers two impacts—the first from the ground impact and the second after sliding into the barrier. In this type of crash, the question arises whether the most harmful event was from the impact with the ground or from the subsequent impact with the guardrail. Similar questions arise in multi-event crashes involving other roadside objects, e.g. trees, utility poles, and concrete barriers.

In the Fatality Analysis Reporting System (FARS), a census of all fatal crashes in the United States, the most harmful event in a crash is determined by specially trained FARS analysts based upon review of police accident reports. Many studies have based their estimates of risk assessment upon the most harmful event. For example, motorcycle collisions with guardrail, where guardrail was designated the most harmful event, have been demonstrated to have a dramatically higher fatality risk than passenger vehicle collisions with guardrail (Gabler, 2007). However, the concern has been raised about whether the guardrail actually was the most harmful event in these crashes. Although the FARS analysts are highly trained, the assessment of most harmful event includes some degree of subjectivity. Perhaps, in a ground–guardrail, two-event crash, the motorcyclist had already received fatal injuries from the ground impact prior to hitting the guardrail. Certainly, both events would contribute to the injury severity, but needed is a non-subjective method to determine which event posed the greater risk in these crashes.

2. Objective

The goal of this study is to determine the fatality risk in motorcycle collisions with roadside objects and collisions with the ground. One specific objective is to determine whether a collision with a roadside object is typically more harmful to a motorcyclist than the collision with the ground.

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3. Methods

The roadside objects included for analysis in this study were guardrails, concrete barriers, trees, signage, and utility poles. The Fatality Analysis Reporting System (FARS) database was used in conjunction with the General Estimates System (GES) database to analyze motorcycle crashes from 2004 to 2008. FARS is a comprehensive census of all US traffic related fatalities that occur within 30 days of a traffic crash (NHTSA, 2008). GES is a database containing information on approximately 60,000 randomly sampled police reported accidents each year (NHTSA, 2008). Cases from GES are assigned weights that can be used to estimate the number of similar non-sampled crashes that may have occurred that year. The FARS and GES cases were combined to determine the fatality risk of particular motorcycle-object event sequences. GES reports all events which occurred in the crash to each vehicle. Beginning in 2004, FARS was enhanced to report up to six events suffered by each vehicle in a crash.

For this study, three independent methods were pursued to determine if the collision with a roadside object is typically more harmful to a motorcyclist than the collision with the ground. These were based on both the most harmful event and the sequence of events.

3.1. Relative fatality risks based on the most harmful event

First, the most harmful event (MHE) was used to compare the fatality risk of fixed object collisions to that of collisions with the ground. The fatality risks of collisions with the various fixed objects were compared to the fatality risks of overturning or colliding with another motor vehicle. Cases coded as an overturn or rollover collision were interpreted as equivalent to a collision with the ground. The fatality risk of each collision event was computed using the equation *Fatality risk* = *Fatal crashes/Total crashes* (Eq. (1)). Confidence bounds on data from GES were found using the methods described in the GES Analytical User's Manual (NHTSA, 2009). These were then used to determine the confidence bounds on the fatality risk ratios.

The number of fatal crashes was determined using the FARS data and the total number of crashes was determined using the GES data. Next, the relative fatality risk of a fixed object collision to collisions with the ground was computed for each fixed object using the equation *Relative fatality risk* = *Fatality risk of roadside object collision/Fatality risk of ground collision* (Eq. (2)).

This component of the analysis was based on the most harmful event (MHE) as coded by the FARS or GES analysts. The sequence of events during the crash was not taken into account. All crashes in which the MHE was reported as either a fixed object or a collision with the ground were used in the analysis.

3.2. Relative fatality risks based on the sequence of events

Next, a similar analysis was conducted using the sequence of events. This provided a method for determining fatality risk independently of the most harmful event. All analyses utilizing the sequence of events are based on the total number of motorcycles involved in crashes, as opposed to the number of crashes. Also, the FARS data reports a more detailed set of events than the GES data, including non-collision events such as "run off road, right" and "cross median". There are 13 such non-collision events included in FARS that are not included in the GES sequence of events.

This analysis compares single-event collisions to the ground to collisions with roadside objects. A crash during which the only events were those with the specified roadside object, an overturn, or one of the aforementioned non-collision events was included. For example, a crash whose reported sequence of events was (1) run off road, right, (2) guardrail face, and (3) overturn was considered a guardrail collision. However, a crash whose reported sequence of events was (1) run off road, right, (2) tree, (3) guardrail, and (4) overturn was not included in the analysis since there was more than one object struck. Overturn events were included since it is assumed that every motorcycle will overturn in a crash due to their unstable nature.

The fatality risk for collisions each fixed object and the ground was computed using Eq. (1) (Section 3.1). Next, the relative fatality risk of fixed object collisions as compared to collisions with the ground was computed using Eq. (2) (Section 3.1).

3.3. Distribution of most harmful event in fatal fixed object–ground crashes

The last component of the analysis specifically explored the question of whether the ground impact or the fixed object impact was more likely to be designated as the most harmful event in a fatal crash reported to involve an overturn *and* a collision with a fixed object. This analysis was limited to fatal, two-event crashes where one event was a collision with the fixed object and the other was a collision with the ground. The fraction of crashes in which overturn was designated as MHE or the given object was designated as MHE was computed and compared. This analysis will show how FARS analysts judged the relative risk of collision with a fixed object or ground for all motorcycles that experienced both collisions exclusively. Confidence bounds were computed based on a Gaussian distribution since FARS contains a census of all fatal crashes.

Table 1
Motorcyclist fatality risk by most harmful object struck (FARS, GES 2004–2008).

Object struck	Fatal crashes	Total crashes	Fatality risk (95% CI)
Guardrail	1,078	7,448	0.145 (0.110–0.211)
Concrete barrier	246	2,978	0.083 (0.057–0.148)
Sign post/utility pole/other support	1,191	5,424	0.220 (0.163–0.338)
Tree	1,178	4,001	0.294 (0.211–0.485)
Motor vehicle	11,513	231,309	0.050 (0.043–0.059)
Rollover/overturn	4,219	209,415	0.020 (0.017–0.024)

4. Results

The three methods of determining the more harmful component of multi-event crashes yielded similar results. The first component of the analysis utilizes the most harmful event as reported in the database. Fatality risks for each collision type were computed using Eq. (1) (Section 3.1). The number of fatal crashes and total crashes in which a fixed object, another motor vehicle, or the ground was reported as the most harmful event is given in Table 1.

Table 1 shows that the most common type of motorcycle crash of those analyzed was either a collision with the ground or with a vehicle in transport. However, it also shows that roadside objects are dramatically overrepresented in fatality risk. For all roadside object collisions analyzed, the fatality risk of fixed object collisions was found to be greater than the risk for either overturn or motor vehicle collisions. Motorcycle–tree collisions had the highest fatality risk, followed by collisions with signage and utility poles. For this analysis, utility pole and signage crashes were included in one category since they are grouped in this way in the GES database.

The outcome of fixed object collisions was then directly compared to the outcome of collisions with the ground using a relative fatality risk (Eq. (2), Section 3.1). Fig. 1 shows the relative risks for each collision type analyzed based on the MHE. Based on this

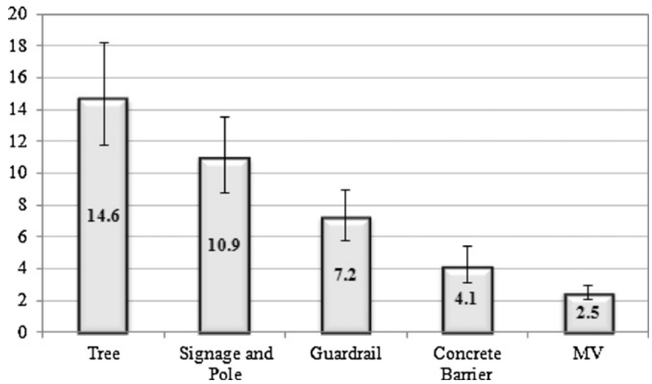

Fig. 1. Relative fatality risk of fixed object collisions based on MHE (FARS, GES 2004–2008).

Table 2
Motorcyclist fatality risk by sequence of events (FARS, GES 2004–2008).

Object struck	Fatal crashes	Total crashes	Fatality risk (95% CI)
Guardrail	701	3,829	0.183 (0.131–0.305)
Concrete barrier	1,014	9,759	0.104 (0.081–0.146)
Sign post/utility pole/other support	693	6,677	0.104 (0.078–0.154)
Tree	206	4,116	0.050 (0.036–0.082)
Rollover/overturn	1,909	174,026	0.011 (0.009–0.013)

analysis, a collision with a guardrail is 7.184 (95% CI: 5.768–8.948) times more likely to be fatal than a collision with the ground. Comparatively, concrete barrier collisions are only 4.10 (95% CI: 3.094–5.433) times more likely to be fatal than collisions with the ground. Even more severe are tree collisions, which are 14.614 (95% CI: 11.757–18.165) times more likely to be fatal. Lastly, the fatality risk for collisions with motor vehicles is greater than the fatality risk for overturn collisions; the relative risk of a collision with another motor vehicle as compared to an overturn collision is 2.471 (95% CI: 2.061–2.962).

Next, a similar analysis was conducted using the sequence of events, which removes the subjectivity of determining the MHE in the collision. As described in Section 3.2, this method compared crashes where the only collision event was with the ground with collisions involving roadside objects and the ground. The fatality risk of collision with each fixed object is shown in Table 2. The relative fatality risk between the roadside object and a collision with the ground was computed (Fig. 2). The relative fatality risks

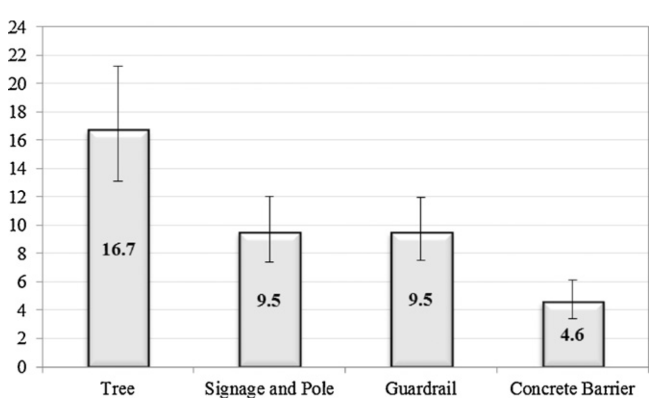

Fig. 2. Relative fatality risk of fixed object collisions based on the sequence of events (FARS, GES 2004–2008).

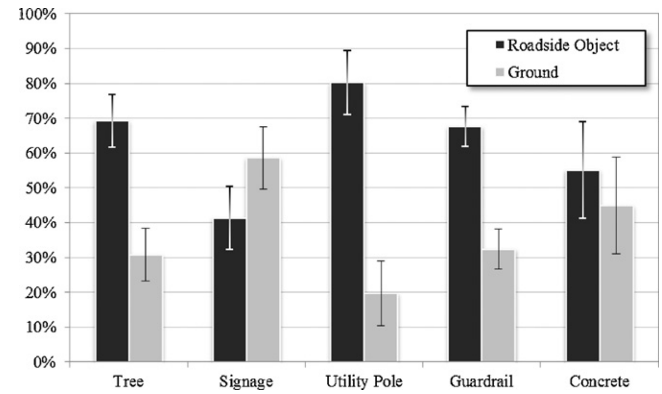

Fig. 3. Distribution of most harmful event in two-event fatal crashes involving a fixed object and ground (FARS, 2004–2008).

computed using this method were not statistically different from those computed based on the MHE.

The final component of the study addressed the question of which event was likely to be designated as the most harmful event in a multi-event crash reported to involve a roadside object and a collision with the ground. Since this analysis was completed using only FARS data, signage and utility poles were divided into separate categories. Fig. 3 shows the distribution of most harmful event for motorcycles in two-event crashes that collided with one of the fixed objects analyzed and the ground.

It should be noted that for most fixed object collisions examined, the fixed object was the most harmful event in the majority of the crashes. Guardrails were designated as the most harmful event in 69.2% (95% CI: 61.7–76.8%) of the multi-event collisions that involved a guardrail. Likewise, utility poles were the most harmful event in 80.3% (95% CI: 71.0–89.5%) of multi-event crashes involving a utility pole.

For all two-event fatal crashes involving only collisions with a fixed object and the ground, the collision with the ground was designated as the most harmful event in less than 37% of the crashes. With the exception of signage, the fixed object was reported to be the most harmful event more frequently than the overturn in all fatal overturn–fixed object collisions analyzed. Signage posts are often designed to be breakaway devices and deform more easily than the other types of fixed object analyzed in this study. The lower percentage of cases where the signage was reported to be the most harmful event is likely attributed to this design difference. The findings of this component of the study are consistent with the relative risk studies (Figs. 1 and 2) in that the collision with the roadside object is most often more harmful than the collision with the ground.

5. Limitations

The findings of this study were based on police reported event sequences in the databases. The FARS and GES databases code events using different categories, making FARS and GES challenging to directly compare. There are fewer types of collisions reported in the GES data; therefore, relative risks of some collisions could not be explored. Additionally, the FARS data is limited to reporting 6 events whereas no limit is placed upon the number of events per cases in GES. The events included in the sequences are those reported in the police accident reports, and therefore depend upon how thoroughly police recorded all events that occurred during a crash. The reported sequence of events may not always be accurate especially for fatal, single vehicle crashes where there were no witnesses to the crash. Lastly, the analyses do not include the influence of additional confounding factors, such as roadway geometry. The effects of these factors may be examined for further information about fatality risk in crashes.

6. Discussion

Several other methods were considered to analyze which aspect of a collision is more likely to cause harm to the motorcyclists. First, the fatality risk was computed based on the sequence of events. Single-event roadside object collisions were compared to crashes where both the collision with the ground and the collision with the roadside object were reported. However, it would be highly unlikely for a motorcycle to not overturn in a collision, so it was assumed that the overturn was likely not coded for these "single event" collisions. In a brief analysis of police accident reports from one state, the overturn was often not coded, though it was described in the synopsis of the crash. Since the overturn was omitted in some cases, the data was not consistent enough to conduct this analysis. A second proposed analysis was to determine the fatality risk based on the number of crash events. However, since overturn was not coded for some crashes, the number of events in a crash could not be consistently determined.

The relative risk analyses presented in this study do not directly consider whether or not a collision with the ground is reported. Therefore, these analyses are not subject to this potential bias. The distribution of most harmful event is based on crashes where the overturn is reported, since the sequence of events in these crashes is assumed to be complete. The aforementioned analyses that were considered would provide more insight into the research question. These types of studies may be possible in Europe using in-depth motorcycle crash databases, e.g. MAIDS (ACEM, 2004). However, in-depth motorcycle crash data currently does not exist for a comparable U.S. study.

7. Conclusions

The goal of this study was to determine the relative fatality risk of motorcycle–barrier collisions vs. motorcycle–ground collisions. This study has shown that motorcycle collisions with guardrail have a greater fatality risk for motorcyclists than collisions with the ground. Based on the most harmful event, collisions with guardrail were 7 times more likely to be fatal. Likewise, all the roadside objects analyzed in this study had a fatality risk at least greater than 4 when compared to collisions with the ground. The fatality risk of colliding with a tree was almost 15 times greater than the fatality risk of an overturn collision. These ratios were also confirmed by determining the relative risk based on the sequence of events; there was no statistical difference found between the relative risk ratios computed using the two methods.

The greater fatality risk for trees as compared to guardrail is consistent with the findings of Tung et al. (2008), who determined that narrow objects have a greater fatality rate than guardrails. They also found that guardrail collisions were more likely to cause serious injury than non-object collisions (Tung et al., 2008), which is also consistent with the findings of this study.

The fixed object was frequently the most harmful event in two-event fatal crashes that exclusively included collisions with a fixed object and the ground; utility poles, guardrails, and trees were reported as the most harmful event in more than 50% of fatal collisions involving each fixed object, respectively. Therefore, with the exception of signage, it is more likely that the roadside object is the most harmful event in crashes including a collision with both a roadside object and the ground.

This study refutes the hypothesis that it is the ground rather than the barrier which fatally injures the rider in a multi-event crash involving a motorcycle which overturns and strikes a guardrail. The fatality risk of striking a guardrail is 7 times greater than the risk of striking the ground. Therefore, on average, a motorcycle–guardrail collision is more harmful than a motorcycle–ground collision. However, the risk of colliding with a guardrail or concrete barrier is significantly lower than the risk of colliding with the object they may be protecting, such as trees or utility poles. Though guardrails have demonstrated to be more harmful to motorcyclists than passengers of other vehicles, they still provide some protection against other roadside objects.

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