Motorcycle Crash Speed and Rider Injury Severity

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Abstract

It seems intuitively obvious that motorcycle rider injury severity should increase as motorcycle crash speed increases. The expected speed-severity relationship has been documented but not very thoroughly described. For this report, data from the three extant on-scene, in-depth motorcycle accident investigations are analyzed: 1) 1,082 motorcycles in Thailand crashes in 1999-2000; 2) 921 cases investigated in Europe for the MAIDS study, and 3) 900 crashes in Los Angeles in 1976-77. The Thailand and MAIDS studies followed the OECD Common International Methodology for motorcycle accident investigation and reconstruction that grew out of the Los Angeles study. Motorcycle crash speed is the focus here because the rider has some control over speed but little or no control over the other variables that influence injury severity once the crash sequence begins. Crash speed and crash speed squared (as a proxy for kinetic energy) were used as independent variables while several measures are used to quantify the dependent variable: 1) the Injury Severity Score, 2) an injury severity score that excludes head, neck and face injuries, 3) the most severe below-the-neck injury, 4) the most severe head-neck-face injury and 5) the most severe brain injury.

Pearson r and Spearman rank-correlation tests showed statistically significant positive correlations of motorcycle crash speed and crash speed squared with the various measures of injury severity. The data show that as crash speed increased, the percentage of low-severity crashes decreased and higher-severity crashes increased. However, the correlation coefficients of all accidents in each study area were rather low for crash speed and for crash speed squared. They were generally in the range of .25-.35. This suggests that the rider's crash speed and his kinetic energy by themselves account for only about 8-12% of the variability in injury severity. These findings were consistent across all three study areas. Speed-severity correlations were usually higher when comparing within a single accident type (such as perpendicular crossing crashes) but even within a single crash configuration motorcycle crash speed itself rarely accounted for more than 25% of the variability of rider injury severity.

Thus, it appears that motorcycle crash speed by itself has only a mild influence on rider injury severity. Aside from helmet use, other factors over which the rider has little or no control have a powerful influence in injury severity.

INTRODUCTION

Higher motorcycle crash speeds should result in more severe injuries for the rider. This obvious connection has been documented but little explored in the past. One reason for this deficit in accurate information about how crash speed affects injury severity is simple: it's expensive and difficult to obtain accurate data on both.

Speed information can rarely be obtained from police reports because few police officers have any training or experience in the analysis of motorcycle accidents. Injury severity data in police reports is also of uncertain reliability, except perhaps in fatalities. Police report injury information is particularly prone to error when a rider suffers serious internal injury that is not readily seen.

However, three large-scale, in-depth motorcycle accident studies have collected reliable speed and injury data. In all three studies, trained investigators conducted a detailed on-scene investigation immediately after a crash. Physical evidence such as skid marks, braking evidence on tires, vehicle damage, etc. was used to calculate accurate crash speed and precrash speeds. The first such study involved 900 accident-involved motorcycles in Los Angeles (Hurt et al., 1981); the second involved 1082 cases in Thailand (Kasantikul, 2002a & 2002b). The third study involved 921 cases investigated by independent teams in five European locations (MAIDS, 2004). Data from all three studies are analyzed in this report.

In the first of these three studies, Hurt et al. (1981, pp 213-215) reported that serious injuries do indeed tend to become more frequent as crash speed increases. Elsewhere, they reported a median crash speed for non-fatal crashes of 20 mph (33 km/hr) and 37 mph (60 km/hr) for fatal crashes (Ouellet et al., 1987).

The MAIDS study of 921 motorcycle crashes in Europe (OECD, 2009, p. 119) likewise reported that as crash speeds increased, low severity injuries became less common while higher severity injuries and fatalities became more common.

The Thailand motorcycle accident study (Kasantikul, 2002a, 2002b) did not directly address the relationship between crash speed and injury severity.

The most detailed study to date (Smith, 2009) used a multiple logistic regression analysis of the MAIDS data to examine the interaction of more than 20 variables on the probability of the rider being killed in a crash. Smith concluded that for very small powered two wheelers (PTWs) – those under 50cc engine displacement – the risk of death increased by 24-84%, for every 10 km/hr increase in speed, depending on the interaction of other variables. For L3 PTWs (those larger than 50cc engine displacement), crash speed itself did not have a significant effect on fatality risk but increased traveling speed – the speed before any braking or evasive action – did increase the rider's risk of being killed.

There is no question that factors other than crash speed affect injury severity. Helmet use, alcohol, roadway design, day-night, rider age and collision configuration have all been shown to affect rider injuries (e.g., Quddus et al, 2006; Savoleinin and Mannering, 2007; Smith, 2009; Schneider and Savoleinin, 2010) All except Smith's 2009 report are multivariate studies drawn from police report data and thus are unable to establish crash speeds in each case and rely on police report information about rider injuries.

The present study focuses only on crash speed, because it is one of the very few variables over which the rider has any control once a precipitating event occurs that turns a normal riding situation into a crisis that results in the crash. Kinetic energy increases as the square of speed and it is kinetic energy the rider's body must absorb and/or dissipate in the course of a crash. Injury is the usual result when the body's energy absorbing capacity is exceeded. Therefore, the square of crash speed is used as an independent variable here as a proxy for kinetic energy.

METHODS

In all three study areas – Los Angeles (1976-77), Thailand and Europe (both 1999-2000), teams of investigators traveled to an accident scene shortly after the crash in order to conduct a detailed research investigation and analysis independent of the police investigation. The investigators were university graduates who had undergone specific training in motorcycle accident investigation and reconstruction, motorcycle design and handling, interviewing, injury analysis, helmet design and analysis, etc.

Investigation teams obtained crash notifications from police or ambulance communication centers. Once on-scene, investigators photographed the motorcycle(s) and other vehicles involved as well as skids, scrapes, "people marks" (such as blood, cloth marks, "soft" dents in vehicles), pre-crash paths of travel, etc. Investigators also measured and diagrammed the physical evidence as well as obtaining driver and witness interviews and injury information. In all three studies, injury data was obtained from riders and medical care providers. The investigators also collected accident-involved helmets, which were later analyzed for damage and collision performance. Finally, they used the evidence to reconstruct the collision events and identify precrash and crash speeds, accident and injury causation and helmet performance.

The so-called Hurt Study (Hurt et al., 1981) involved 900 accidents at all levels of severity in the City of Los Angeles in 1976-77.

The Thailand study investigated a total of 969 collisions involving 1082 riders and 399 passengers in six different regions within Thailand over a twenty month period. About one-fourth of the Thailand multiple-vehicle collisions involved two motorcycles, so that there were more motorcycles than collisions. If two motorcycles collided, each motorcycle was considered a separate case. The first twelve months of the Thailand study (all of 1999) were devoted to accident investigation in Bangkok (723 cases). In the remaining months (March – September, 2000) another 359 cases were investigated in “upcountry” sampling regions of Thailand (i.e., the provinces of Phetchburi, Trang, Khon Kaen, Saraburi and Chiang Rai), which were located 150 to 700 km from Bangkok.

The MAIDS study in Europe involved five independent teams located in France, Germany, Netherlands, Spain and Italy who investigated a total of 921 cases.

The crash investigation and reconstruction methodology used in the Thailand and MAIDS studies was essentially the same as that used in Los Angeles, and has been described elsewhere in more detail (Severy et al., 1970; Ouellet, 1979; Lambourn, 1991; Baxter, 1996; Wood et al, 2008; Bartlett et al., 2013). In Thailand and Europe, approximately 2000 data elements were recorded, using the OECD data form. Some data elements were simple items such as weather, roadway type, motorcycle manufacturer or rider gender. Other items were complex factors that required considerable analysis and integration of accident evidence, such as precrash and crash speeds, injury mechanisms, accident cause factors and helmet performance.

Because so little motorcycle crash testing is available in the scientific literature, and because motorcycle and rider crash motions are so complex, speed analysis in motorcycle accidents remains as much art as science. On-scene investigators record a variety of information including points of impact and rest of motorcycle(s) and rider(s), the lengths and directions of skids and scrape marks on the pavement, damage to the motorcycle and other vehicle(s), etc. Nonetheless, reconstruction of speed requires a judicious selection of from a variety of techniques for estimating speed.

Generally speaking, speed is lost in three areas: during precrash braking and/or sliding, in collision impact damage and in post crash motion. Typical deceleration rates can be used for the precrash and post-crash speed loss calculations, but analysis of collision impact damage is much more complex. For example, motorcycle front end crush, even in comparable crashes, can be very different depending on whether the motorcycle has a wire-spoke wheel that can crush inward toward the axle with relative ease or a cast alloy wheel, which is much more rigid and therefore likely to twist to one side than to crush. Motorcycle front end crush can also vary depending on how fast the opposing vehicle is moving across the path of the motorcycle and what part of the vehicle the motorcycle hits (for example, car wheels are much harder than car doors). The motorcycle may be upright on both wheels (or, occasionally, one wheel) or it may be down sliding as the result of precrash loss of control.

These complications make identification of exact crash speed difficult. The reader should keep in mind that crash speeds cited here usually have an error estimate of about ±5-10 km/hr. Occasionally a crash yields very precise speed estimates, such as when a rider ejects over a bridge or overpass and falls to the ground below. In such a case, the vertical height can be used to calculate a precise free-fall time (denominator), and the horizontal distance traveled during the free-fall provides a numerator that allows calculating rider speed, using the simple formula, velocity = distance / time. However, such cases are the exception, while ambiguity and uncertainty remain the rule.

The MAIDS and Thailand injury data were coded using the 1998 version of *The Abbreviated Injury Scale* (AAAM, 1998). Brain injuries reported in this paper included the following AIS-98 codes: crush (11300.6), intracranial blood vessel injuries (12099.3 – 122806.3), brain & meningeal injuries (140299.5 – 140799.3), skull injuries(150200.3 – 150408.4) and loss of consciousness (160202.2 – 161000.2).

The USC somatic (i.e., below-the-neck) injury data was coded using the Occupant Injury Classification (Marsh, 1973). Head injuries were coded using a similar system described by Ouellet et al (1984). A rider was coded as having a brain injury if the injured system-organ was the brainstem, neocortex, subcortex, cerebellum, epidural, subdural or subarachnoid spaces, or if a skull vault or basal fracture was coded in lieu of a discrete brain injury (such as skull fracture with alteration of consciousness.) Injury severity in the USC data was coded in accordance with the 1980 revision of *The Abbreviated Injury Scale* (AAAM, 1980). The use of different versions of *The Abbreviated Injury Scale* should not be a problem because brain injury severity classifications were nearly identical in the two versions of the AIS and because all statistical comparisons reported here are made within each database, never across databases.

Medical treatment in Thailand and Los Angeles was classified on an ordinal scale in which 1 = treated on scene, no transport to hospital; 2 = treated in emergency room and released; 3 = admitted to hospital; 4 = fatal.

Cases are included only if both crash speed and injury severity data were known, so the number of cases may vary slightly from one comparison to another.

RESULTS

The median crash speed in Los Angeles motorcycle crashes was 35 km/hr (22 mph). In Thailand, the median crash speed was 30 km/hr (19 mph). Speeds in Thailand were generally lower than in Los Angeles. In the European MAIDS study, the median crash speed for all PTWs combined was about 38 km/hr (23 mph). However, the median for L1 category PTWs (those 50cc or less) was 30 km/hr (18 mph) while L3 vehicles (>50cc) had a median crash speed of 47 km/hr (30 mph). Figure 1 shows the cumulative percent distribution of motorcycle crash speed in all three study areas.

Table 1 shows the distribution of the rider's most severe somatic (that is, below-the-neck) injury for Thailand, Los Angeles and the MAIDS study. Thailand had far more riders with AIS<2 injuries than Los Angeles (76.5% vs. 58.5%), while fewer than 40% of riders in Europe had such minor injuries. However, Thailand and Los Angeles had similar percentages of riders in the AIS 4-6 range (3.9% and 4.5%).

Figure 1. Cumulative percent distribution of motorcycle crash speeds in the Thailand, Los Angeles and MAIDS studies

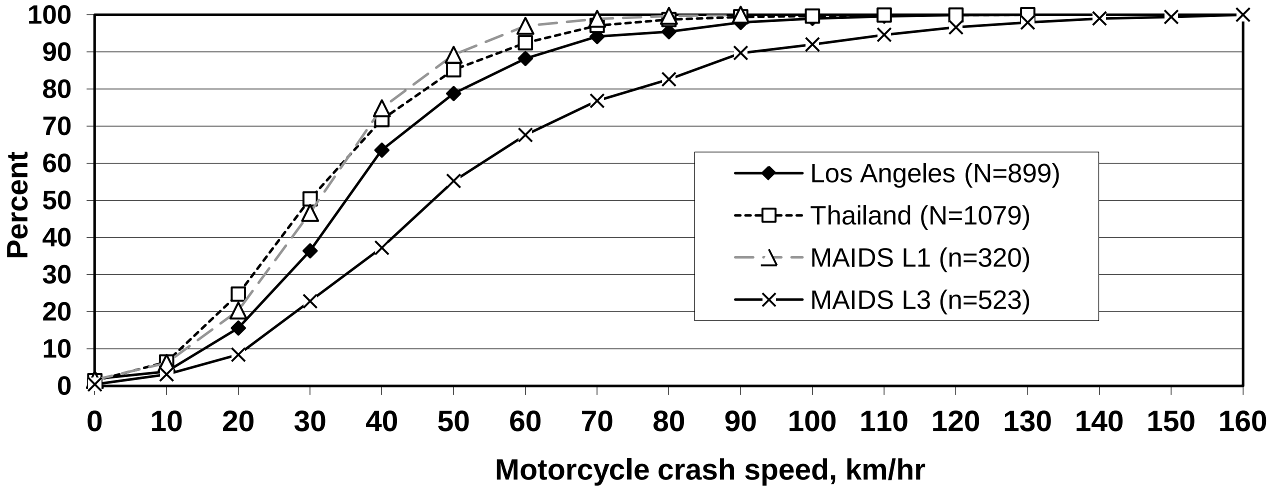


Table 1. Rider most severe somatic (below-the-neck) injury for Los Angeles and Thailand.

Most Severe Somatic Injury	Los Angeles		Thailand		Europe – MAIDS*	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
0 –None	33	3.7	53	4.9	12	1.3
1 – Minor	493	54.8	775	71.6	350	38.0
2 – Moderate	192	21.3	122	11.3	319	34.6
3 – Serious	141	15.7	89	8.2	148	16.1
4 – Severe	10	1.1	21	1.9	36	3.9
5 – Critical	20	2.2	20	1.8	40	4.3
6 - Unsurvivable	11	1.2	2	0.2	17	1.8
Total	900	100.0	1082	100.0	921	100.0

*MAIDS data includes all body regions, not only those below the neck

Table 2. Rider most severe brain injury in Thailand and Los Angeles. MAIDS data includes all injuries the head region, not restricted to brain injuries.

Most Severe Brain Injury	Los Angeles		Thailand		MAIDS – Europe	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
0 –None	761	84.6	930	86.0	278	30.2
1 – Minor	31	3.4	75	6.9	213	23.1
2 – Moderate	37	4.1	10	0.9	257	27.9
3 – Serious	19	2.1	20	1.8	70	7.6
4 – Severe	11	1.2	35	3.2	46	5.0
5 – Critical	27	3.0	9	0.8	51	5.5
6 - Unsurvivable	14	1.6	3	0.3	6	0.7
Total	900	100.0	1082	100.0	921	100.0

Table 2 shows the percent distribution of the rider's most severe brain injury for Los Angeles and Thailand. In both study areas, only about 15% of riders suffered some kind of brain injury. Riders in Los Angeles were somewhat more likely to suffer AIS>2 brain injury than riders in Thailand (8% vs. 6%) even though proper helmet use was approximately 50% in both areas.

Los Angeles

In Los Angeles motorcycle accidents, crash speed was positively correlated with injury severity and medical treatment. Table 3 shows the Pearson r and Spearman rho correlations of various measures of injury severity with motorcycle crash speed and crash speed squared (again, because kinetic energy increases as the square of speed). Because the Spearman rho is calculated by ranking values from lowest to highest, those rankings do not change when the speed is squared. Therefore the Spearman rho correlation coefficient is the same whether calculating with crash speed or crash speed squared. The Pearson r and Spearman rho correlations range from .279 to .390. The squared values of the correlations range from .085 to .15, indicating that crash speed by itself accounted for roughly 8-15% of the variation in injury severity in Los Angeles.

Table 3. Pearson r and Spearman rho correlation coefficients of various measures of injury severity with crash speed and crash speed squared (as a proxy for kinetic energy). All correlations are significant at the .01 level or beyond.

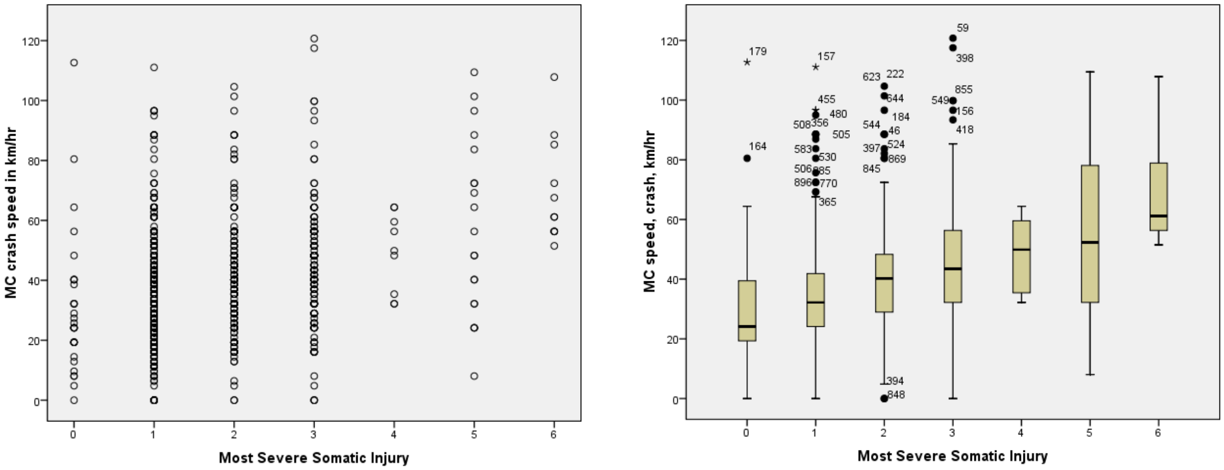
Injury Measure	Pearson r correlations		Spearman rho correlations, V_{crash} or V^2_{crash}
	Crash Speed (V_{crash})	Crash Speed Squared (V^2_{crash})	
Injury Severity Score (ISS)	.374	.382	.361
Somatic ISS	.325	.340	.318
Most Severe Somatic injury	.319	.305	.300
Most Severe Head-Neck Injury	.337	.323	.279
Most Severe Brain Injury	.307	.291	.284
Medical Treatment	.390	.364	.378

In Table 3, brain injury severity correlations tend to be lower than the other measures of injury severity, possibly due to confounding by the effect of helmet use or non-use.

Figure 2 shows a scatter-plot (left) of crash speed and the associated injury severity for each case. The right half of Figure 2 shows a box-plot of crash speeds at each level of injury severity. In the box-plot figures, the upper and lower boundaries of each box represent 75th and 25th percentile speeds respectively, while the horizontal band in the middle of the box is the median (50th) percentile speed. The T-shaped "whiskers" that extend above and below the boxes represent the normal expected range of speeds.

The dots above each “whisker” are considered “outliers” whose speed is more than 1½ times the range of speeds between the 25th and 75th percentiles above the 75th percentile. (More simply, 1.5 times the height of the box beyond the upper or lower border of the box.)

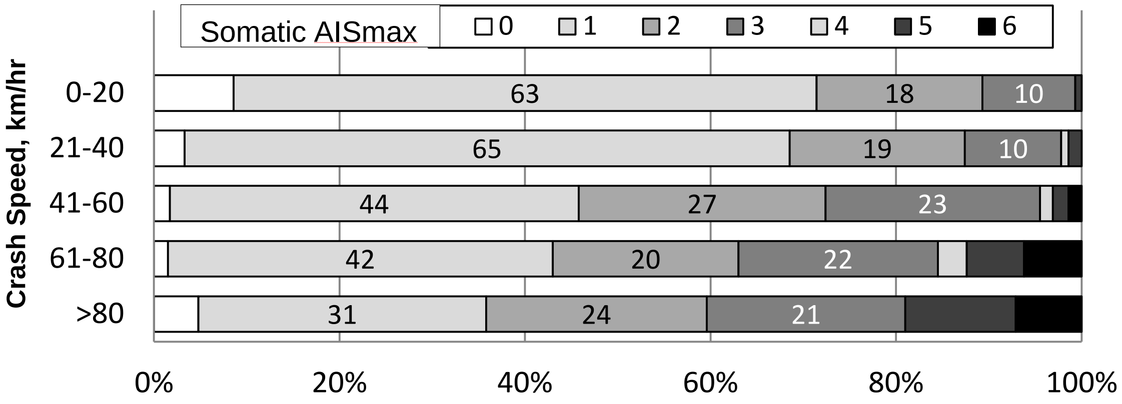
Figure 2. Scatter-plot and box-plot distributions of motorcycle crash speeds for each level of most severe somatic injury in Los Angeles.



A couple things are readily apparent in the scatter plot in Figure 2: one is the dominance of low severity injuries at all crash speeds. Second, each one-step increase in injury severity was associated with a 6 km/hr increase in median crash speed.

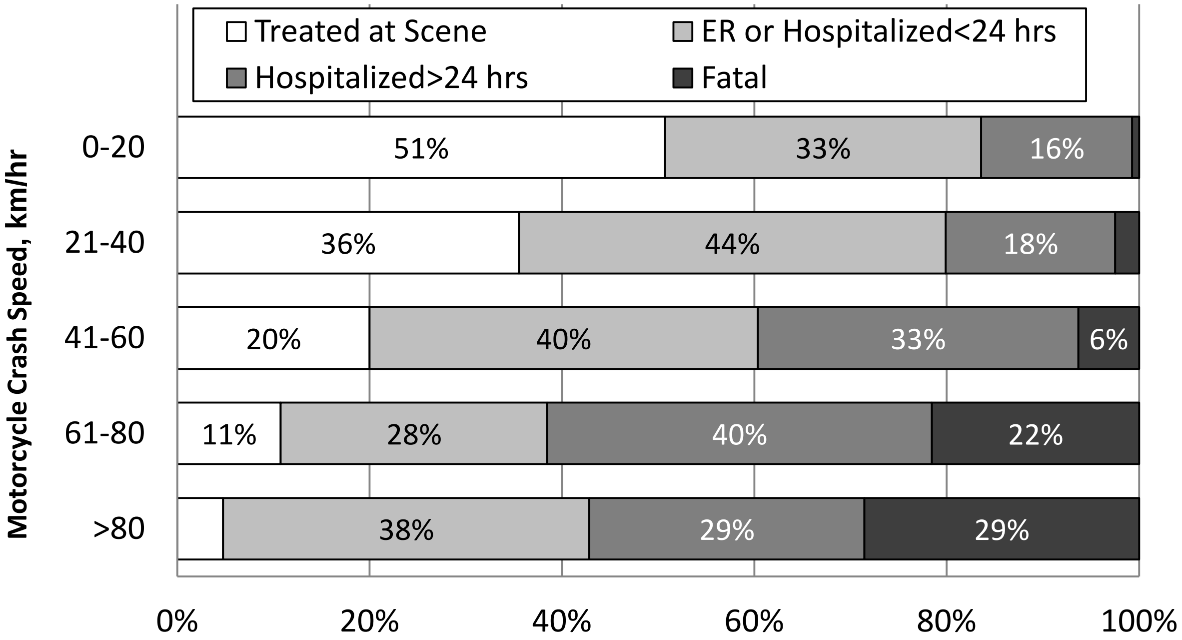
Figure 3 illustrates the distribution of most severe somatic injury in different speed ranges. As speed increases, AIS<2 injuries decline from about 70% of riders to about 40%, while AIS>2 injuries increase, especially at crash speeds over 60 km/hr (37 mph).

Figure 3. Distribution of Most Severe Somatic Injury in different speed ranges.



The positive correlation of motorcycle crash speed with injury severity is confirmed by the post-crash medical status of the rider, as shown in Figure 4. As crash speed increased, the number of riders who were treated on scene but not transported to the emergency room declined steadily. Hospitalization for longer than 24 hours increased steadily at crash speeds above 25 km/hr (15 mph). The fatality rate remained very low (below 5%) at speeds below 48 km/hr (30 mph) but began to increase sharply at speeds above 50 km/hr. Only the frequency of riders with very brief hospitalization (under 24 hours) seemed not to have any obvious relationship to crash speed.

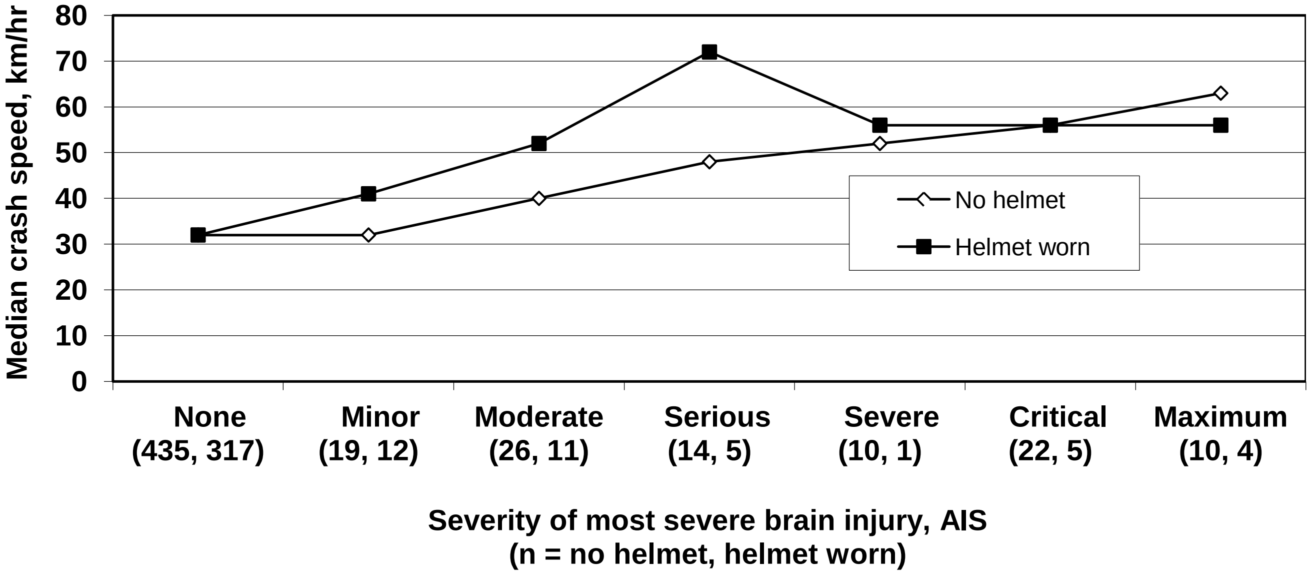
Figure 4. Rider post-crash medical treatment as a function of crash speed, Los Angeles.



Motorcycle crash speed and crash speed squared also correlated in a significant positive manner with brain injury severity, with coefficients near .30. Again, this suggests that crash speed or speed squared accounts for about 8-9% of the variability in brain injury severity.

Figure 5 shows that for unhelmeted riders, as the severity of brain injury increased, the median crash speed tended to increase steadily. From BAIS-1 to BAIS-6, the average increase was 6 km/hr for each increase in one level of severity. The relationship was less clear for helmeted riders. Although the median crash speed tended to increase as brain injury severity increased, the rise was not monotonic and was probably affected strongly by the very limited number of helmeted riders with AIS>2 brain injury.

Figure 5. Median crash speed at each level of most severe brain injury for helmeted and unhelmeted riders in Los Angeles



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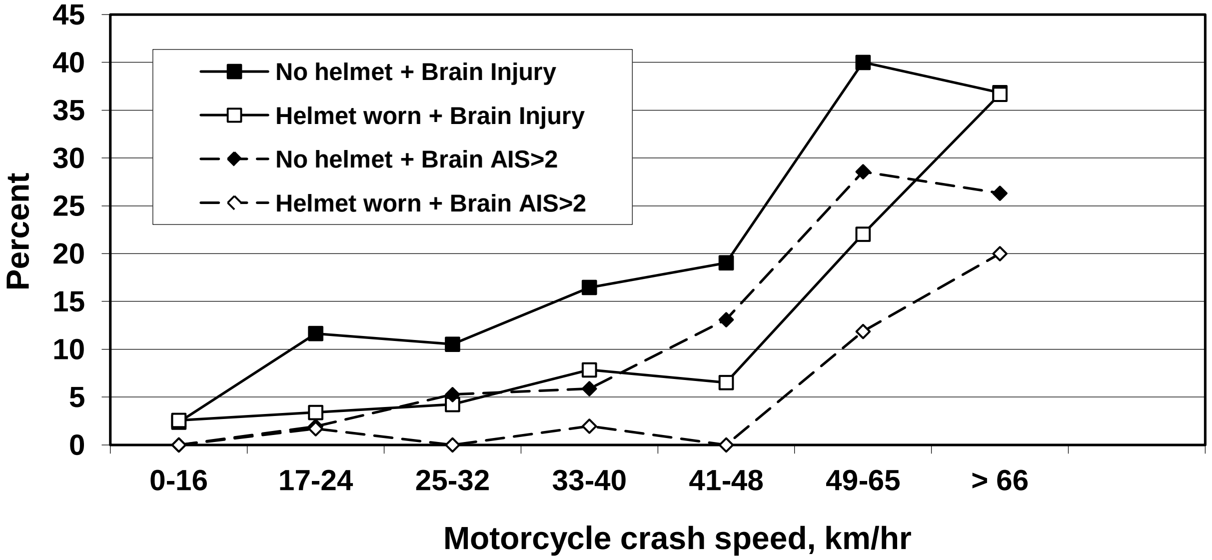
Helmet use does affect the frequency and severity of brain injuries across the speed spectrum, as illustrated in Figure 6, which shows that the rate of brain injury at any level of severity (BAIS>0) among helmeted riders remains is lower than that for unhelmeted riders in every speed range. Only two AIS>2 brain injuries occurred among the 266 helmeted riders (0.75%) who crashed at a speed below 48 km/hr (30 mph), compared to 24 of 428 unhelmeted riders (5.6%). For unhelmeted riders, brain injury rates (BAIS>0) increased steadily as speed rose. In particular, serious brain injury rates (BAIS>2) increased moderately up to crash speeds of 40 km/hr (25 mph), then rose much more quickly at speeds over about 48 km/hr (30 mph). The trend becomes obscured at crash speeds over 65 km/hr largely because so few crashes (7.5%) fell into that speed range, so a change in one or two cases can have a large percentage change.

Figure 6. Frequency of brain injuries in different speed ranges for helmeted and unhelmeted riders in Los Angeles. BAIS>0 means the rider had brain injury that could range AIS 1-6. BAIS>2 represents the more serious brain injuries.



One can, of course, argue that to the effect of motorcycle crash speeds should not be compared across different types of accidents, that speed comparisons are valid only within a given crash configuration. Table 4 presents speed-injury correlations for four common accident configurations that, together, accounted for 56% of the 900 Los Angeles crashes.

When comparing only within an accident configuration, correlation coefficients increase substantially from roughly .30 - .36 (when lumping all accident configurations together) to roughly the range of .40 - .55, at least for three of the four configurations. This suggests that when comparing within a given crash configuration, motorcycle crash speed can account for 15 – 35% of the variation in rider injury severity. Oddly, the correlations drop to near zero in crashes where the motorcycle is upright when it runs off the road. (Many “motorcycle fell on roadway” crashes involved a motorcycle that initially fell on the roadway then slid off the road into barriers or into parked cars. It had the highest fatality rate of all configurations.)

Table 4. Correlations of injury severity with crash speed within four accident configurations in Los Angeles, 1976-77.

Injury Measure	Pearson r correlations		Spearman rho correlations, V_{crash} or V^2_{crash}
	Crash Speed (V_{crash})	Crash Speed Squared (V^2_{crash})	
Car turns left in front of motorcycle approaching from opposite direction (n=194)			
Injury Severity Score (ISS)	.449	.497	.503
Somatic ISS	.421	.481	.475
Most Severe Somatic injury	.468	.503	.454
Most Severe Head-Neck Injury	.357	.337	.352
Most Severe Brain Injury	.336	.332	.319
Medical Treatment	.409	.423	.401
Car crosses motorcycle path perpendicularly (n = 123)			
Injury Severity Score (ISS)	.426	.488	.440
Somatic ISS	.259	.298	.417
Most Severe Somatic injury	.385	.415	.390
Most Severe Head-Neck Injury	.425	.479	.236
Most Severe Brain Injury	.440	.500	.306
Medical Treatment	.432	.462	.399
Motorcycle fell on roadway (n = 143)			
Injury Severity Score (ISS)	.572	.604	.455
Somatic ISS	.522	.562	.340
Most Severe Somatic injury	.518	.538	.368
Most Severe Head-Neck Injury	.514	.510	.459
Most Severe Brain Injury	.437	.430	.421
Medical Treatment	.566	.550	.496
Motorcycle ran off roadway (n=46)			
Injury Severity Score (ISS)	.011	-.027	.039
Somatic ISS	-.175	-.167	.151
Most Severe Somatic injury	-.120	-.159	-.121
Most Severe Head-Neck Injury	.082	.045	.053
Most Severe Brain Injury	.093	.034	.173
Medical Treatment	.151	.117	.131

Thailand

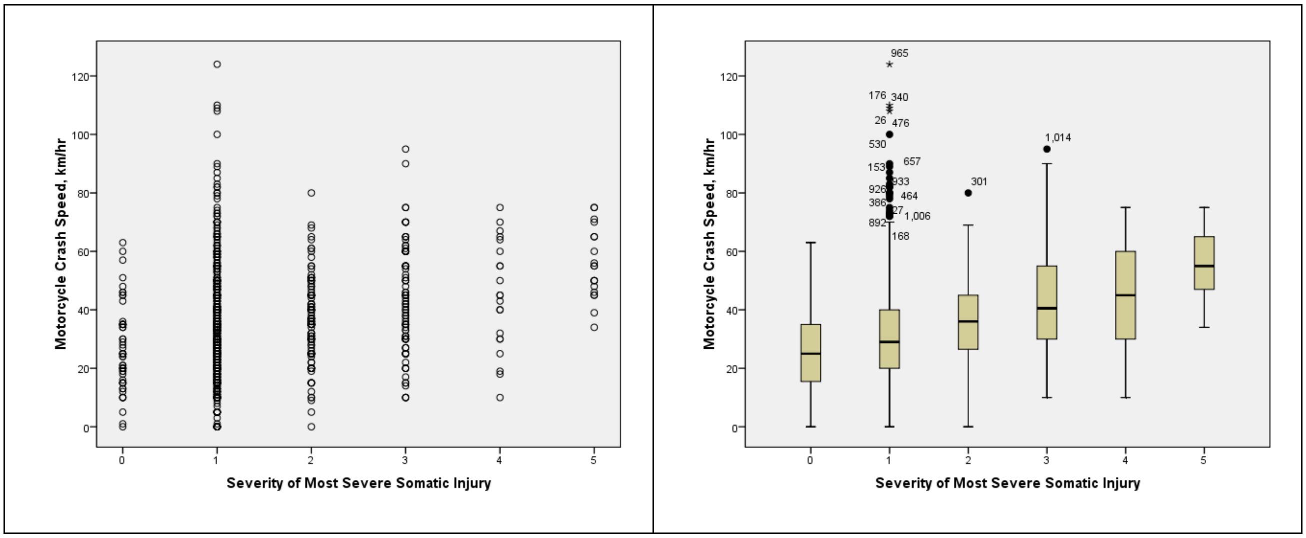
In Thailand, motorcycle crash speed was also positively correlated the various measures of injury severity and the correlations were statistically significant, but generally lower than in Los Angeles. That is, crash speed accounted for less than 10% of the variability in the most severe somatic injury. Figure 7 shows the scatter-plot and box-plot distributions of crash speed for each level of the most severe somatic injury.

The correlations of motorcycle crash speed, crash speed squared and various measures of injury severity are shown in Table 5. All the correlations were positive and significant at the .01 level, but most correlations were approximately .25 ± .03. The main exception was brain injury severity where the correlation was below .20. That is, crash speed by itself accounted for about 5% of the variability in injury severity.

Table 5. Correlation coefficients of Thailand crash speed (V_{crash}) or crash speed squared (V^2_{crash}) with various measurements of injury severity. All were significant at the .01 level.

Injury Measure	Pearson r correlations		Spearman rho correlations, V_{crash} or V^2_{crash}
	Crash Speed (V_{crash})	Crash Speed Squared (V^2_{crash})	
Injury Severity Score (ISS)	.253	.230	.369
Somatic ISS	.287	.287	.287
Most Severe Somatic injury	.263	.234	.263
Most Severe Head-Neck Injury	.313	.256	.313
Most Severe Brain Injury	.176	.174	.176
Medical Treatment	.266	.221	.286

Figure 7. Scatter-plot (left) and box-plot (right) distributions of motorcycle crash speed by most severe somatic injury in Thailand.



As in Los Angeles, each one-step increase the severity of the most severe somatic injury, the speed range was associated with a 6 km/hr increase in the median crash speed. Note that the even highest speed crashes in Thailand were dominated by low injury severity.

Figure 8 shows the distribution of the most severe somatic injury severity in different speed ranges. The most obvious difference is that AIS-1 (Minor) injuries decline from nearly 80% at crash speeds under 25 km/hr (15 mph) to about 59% in the at speeds over about 50 km/hr (30 mph), while more severe injuries become more common at higher speeds.

Figure 8. Thailand: Median crash speed at each level of most severe somatic injury. Values under 5% are shown but not labeled.

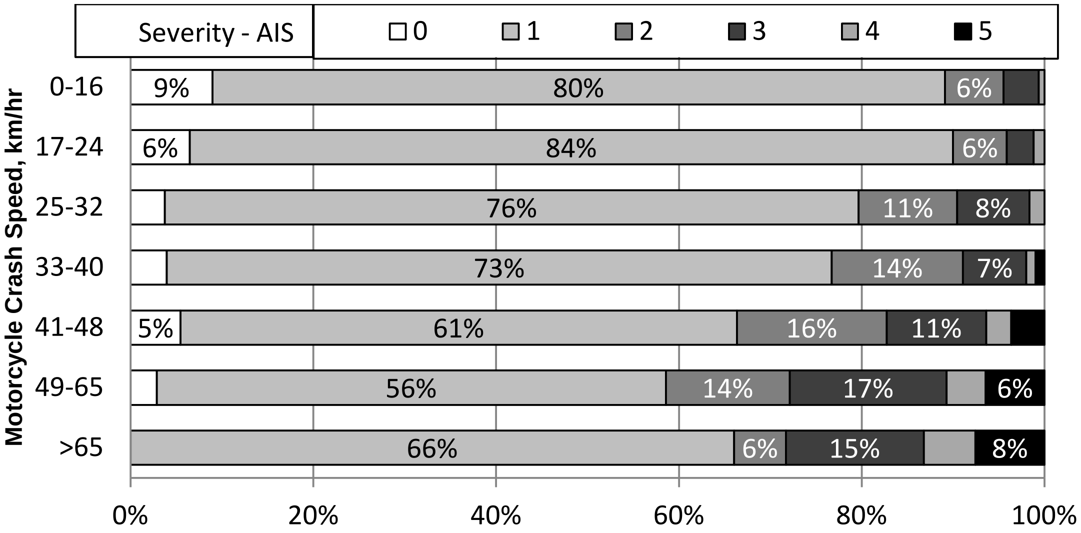


Figure 9 shows that the frequency of serious (AIS>2) brain injury varied depending on helmet use and whether the helmet remained on the rider's head or was ejected (about one-fourth of helmets were ejected, usually due to failures of proper sizing or fastening.) For unhelmeted riders, the frequency of brain injury increased mildly (from 6% to 9.4%) at speeds above 32 km/hr (20 mph), but for helmeted riders the frequency of brain injury remained essentially flat. Brain injury rates varied much more for riders whose helmet ejected, but the trend was toward fewer serious brain injuries as crash speeds increased.

The tenuous relationship between crash speed and injury severity in Thailand is confirmed by the post-crash medical status of the riders, as shown in Figure 10. The percentage of riders who required only first aid at the scene began to decline only when crash speeds exceeded 48 km/hr (30 mph). At speeds above 48 km/hr, the other treatments increased, but none increased sharply. That is to say, riders who required additional treatment beyond first aid at the scene were distributed more or less evenly among the other treatment modalities.

Figure 9. Thailand, frequency of serious (AIS>2) brain injury as a function of helmet use and crash speed

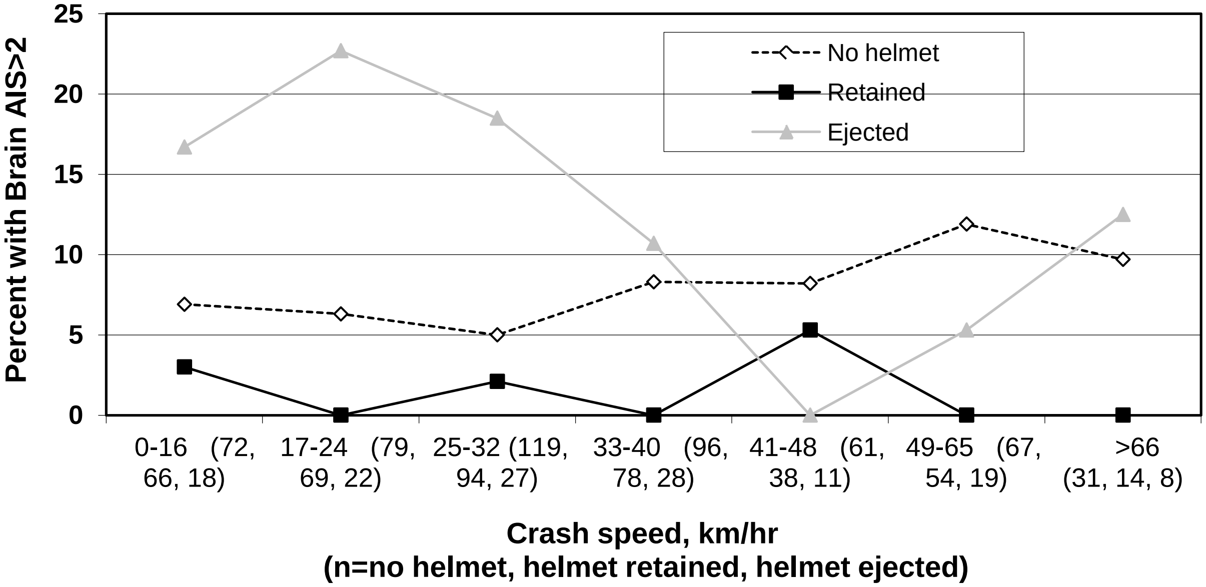
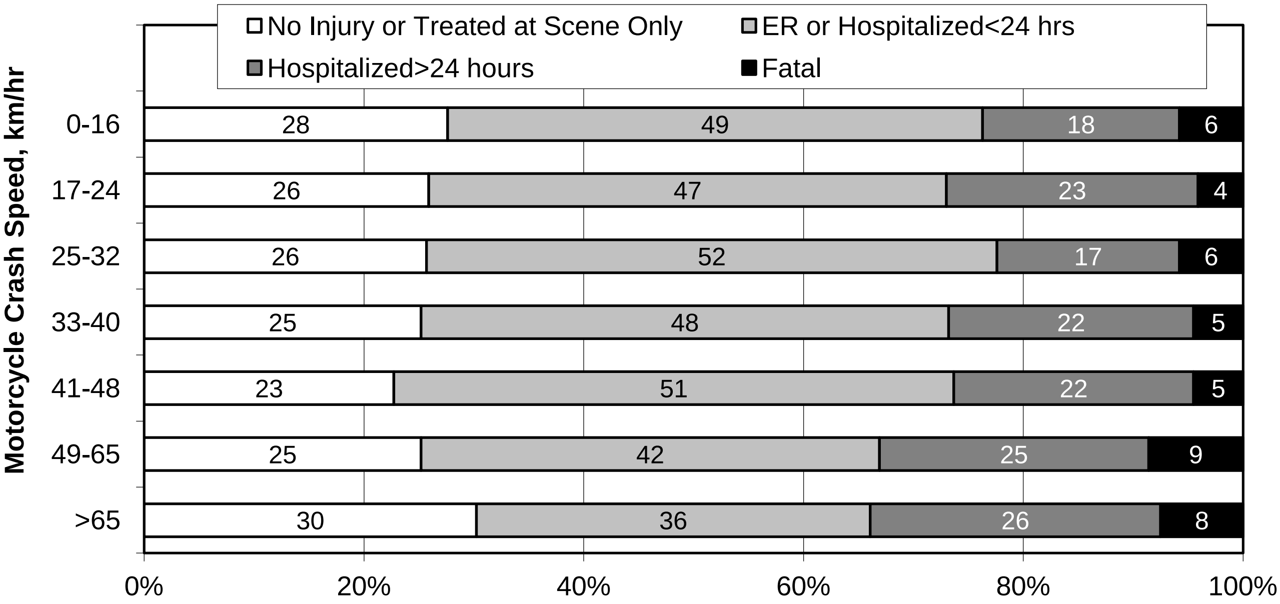


Figure 10. Thailand, rider post-crash medical status as a function of crash speed



Europe - the MAIDS study

Data from the Motorcycle Accident In-Depth Study (MAIDS) in Europe was handled slightly differently than the Los Angeles and Thailand data by coding injury data as the most severe injury in each of the AIS regions: head, neck, upper extremities, spinal column, thorax, abdomen, lower extremities and pelvic contents.

Table 6 shows the Pearson r and Spearman rho correlations of crash speed with the most severe injury in each of those regions. All correlations except throat injuries were statistically significant beyond the .01 level.

Table 6 Correlation coefficients of crash speed (V_{crash}) or crash speed squared (V^2_{crash}) with various measurements of injury severity in the MAIDS study in Europe. All correlations except throat injuries were significant at the .001 level.

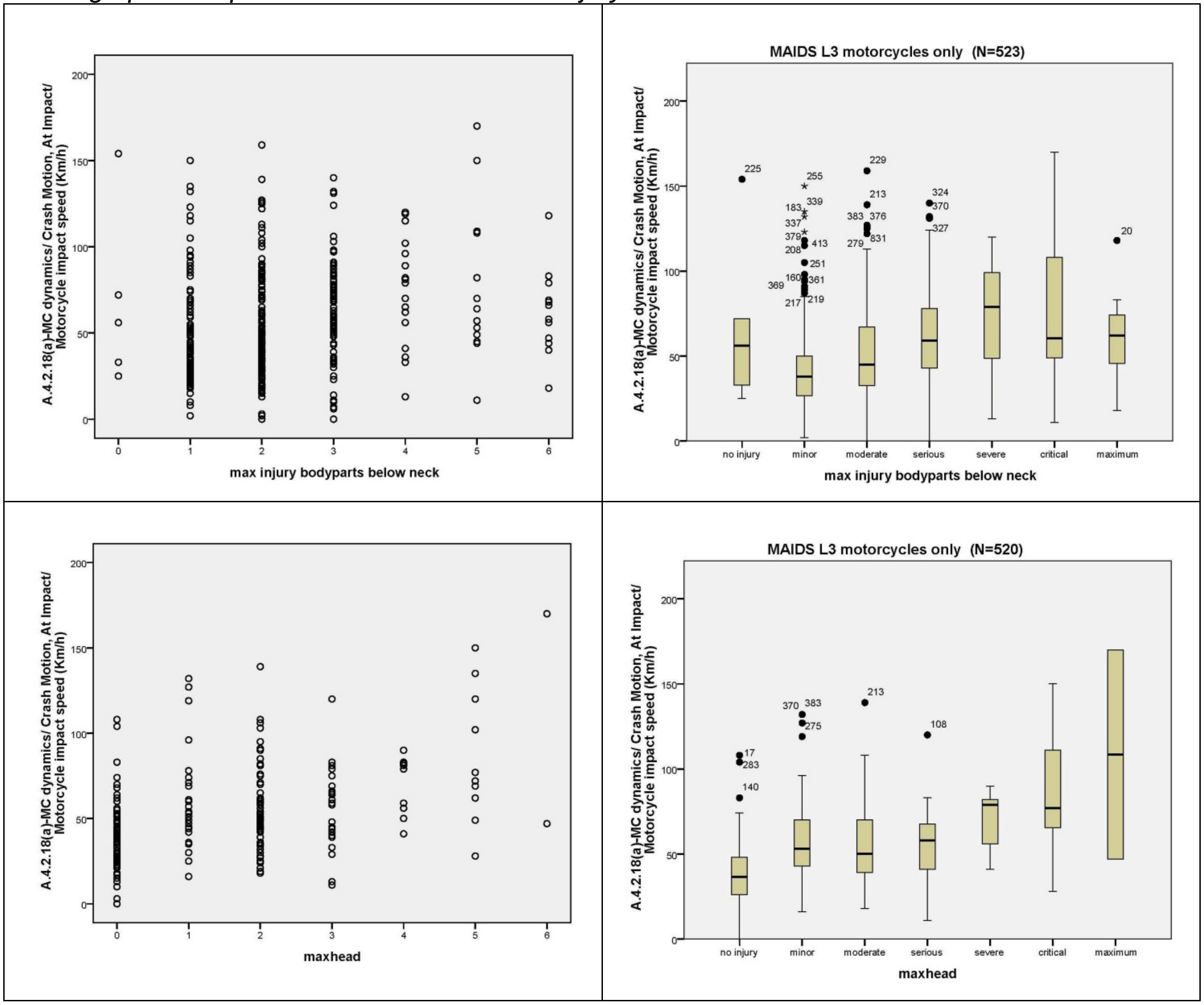
Most Severe Injury by Region	All Powered Two Wheelers (N=920)			PTWs > 50cc (n=522)		
	Pearson r correlation		Spearman ρ V_{crash} or V^2_{crash}	Pearson r correlation		Spearman ρ
	V_{crash}	V^2_{crash}		V_{crash}	V^2_{crash}	V_{crash}
All Regions	.313	.307	.345	.301	.263	.352
Head	.315	.311	.285	.464	.437	.454
Head-Neck	-	-	-	.427	-	.429
Neck - Throat	.054*	.042*	.073*	.082*	.059*	.165
Somatic	-	-	-	.265	-	.322
Upper Extremities	.149	.131	.158	.170	.149	.180
Thorax	.324	.295	.372	.354	.323	.428
Abdomen	.295	.267	.246	.299	.266	.282
Pelvic	.443	.477	.317	.459	.476	.361
Spine	.320	.309	.267	.332	.296	.351
Lower Extremities	.242	.242	.216	.269	.265	.266

* $p > .25$

However, as in Los Angeles and Thailand, the correlation coefficients rarely exceeded .35. The highest r^2 value was .215 while the average r^2 value was around .10. That is, crash speed by itself appears to account for about 10% to as much as 20% of the variability in injury severity in the MAIDS study.

Figure 11 shows the scatter-plot (left) and box-plot (right) diagrams of rider injury severity as a function of crash speed for the 523 motorcycles with an engine displacement over 50cc. The two upper graphs show the data for somatic (below-the-neck) injuries, while the lower two graphs portray the speed-severity relationship for rider head injuries (which included but were not restricted to brain injuries).

Figure 11. Scatter-plot (left) and box-plot (right) diagrams of MAIDS speed versus injury severity comparisons. Upper graphs portray the most severe somatic (below-the-neck) data; lower graphs compare the most severe head injury.



MAIDS hospitalization data cannot be compared directly to Los Angeles and Thailand data. In Europe, any treatment in a hospital was categorized as less than nine days or, alternatively, nine days or longer. In Los Angeles and Thailand, the dividing line was 24 hours. Because the majority (56%) of European riders were classified as being hospitalized less than nine days, it is not possible to say how that large group of riders would be classified in Los Angeles or Thailand. Generally speaking, riders in the MAIDS study tended to be somewhat more seriously injured than those in Thailand or Los Angeles, partly because of differences in data collection methods (Ouellet, 2006). For example, about 10% of MAIDS cases were fatal crashes, compared to roughly 5-6% in Los Angeles (54 of 900), Thailand (63 of 1082) and the U.S. in 2011 (4,612 of 85,000; NHTSA, 2013).

Discussion

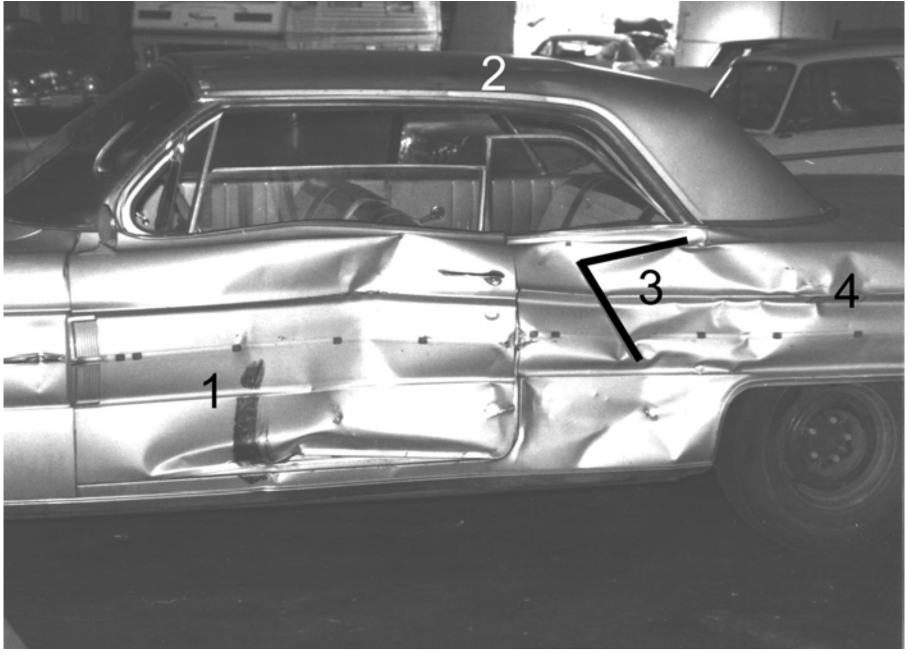
The three study areas reported here were each on different continents, included different cultures and were widely dispersed over decades. Despite this, they correspond closely in two findings: 1) increased injury severity is significantly correlated with increased crash speed – generally, each one-step increase in somatic injury severity shows a 6 km/hr increase in crash speed, and 2) the correlation coefficients of crash speed or crash speed squared (as a substitute for kinetic energy) with injury severity tend to be rather low, generally in the .20 to .40 range. This suggests that within a linear model crash speed and speed squared alone account for about 5-15% of the variability in injury severity in the accident population. Even when comparing only within a given collision configuration, the speed-injury correlation coefficients are usually higher, but motorcycle crash speed by itself generally does not account for more than about 30% of the variation in injury severity.

Generally speaking, as motorcycle crash speed increased, the proportion of crashes with less severe injuries (and lower levels of medical treatment) declined, while more severe injuries and fatalities increased, particularly at crash speeds over about 50 km/hr (30 mph.) However, severe or fatal injuries can still occur even at very low crash speeds while relatively minor injuries occur even at very high speeds.

The low correlation of crash speed squared (as a measure of kinetic energy, which increases as square of speed) and injury severity is a surprise. Generally, correlations of injury severity with crash speed and crash speed squared fell into the same range. The low correlation suggests that other factors, many of them beyond the rider's control, can overwhelm the practical significance of motorcycle crash speed in determining rider injury severity. This was most obvious in run-off-road crashes where the speed / injury severity correlation fell to near-randomness, probably because of the variety of objects awaiting a rider who runs off the road: parked cars, "protective" barriers, boulders, trees, poles, mailboxes, cliffs and drops from elevated roadways, etc. – or nothing.

Figure 12 helps illustrates the complexity of the speed-injury severity relationship. In this motorcycle-car crash, the car crossed the motorcycle path perpendicularly. The sequence of contacts on the left side of the car is numbered: 1) is the contact of the motorcycle front tire on the car door. Impact caused the motorcycle rear tire to pitch upward while the car's right-to-left motion across the motorcycle's path caused the motorcycle to yaw to the right and "slap" against the car's left side. Impact #2 is the faint dent of the rider's head impact on the car roof rail, which caused his fatal head injuries; 3 is the imprint of the rider's right leg; 4 is a dent from the passenger's right leg. She suffered a femur fracture while tumbling over the rear of the car but survived. Both were going the same speed and hit the same car but one died while the other survived, apparently because of the bad or good fortune of striking or not striking the passenger compartment of the car. The injuries certainly would have been very different if the motorcycle had struck the car at the front wheel or the rear quarter-panel. This sort of small difference – a couple tenths of a second in arrival time at the point of impact -- with large effects turns up frequently in motorcycle crashes.

Figure 12. Motorcycle contact marks along the left side of a car that crossed the motorcycle path perpendicularly. 1) Motorcycle front tire, 2) rider's face, 3) rider's right leg, 4) passenger's right leg.



For the overall population of riders involved in crashes, more speed reduction before impact is better. For the individual rider, the benefit of speed reduction in his or her crash is less unpredictable because crash speed interacts with the detailed circumstances of the crash as illustrated by the collision in Figure 12.

The author has previously suggested that the potential for even skilled braking to prevent a crash may be very limited depending on a rider's location relative to a car about to cross his path (Ouellet, 1991). Worse, only about 10-15% of riders in the Los Angeles study chose the proper evasive action and then executed it properly, regardless of their training (Ouellet & Kasantikul, 2006). In the latter report, nearly one in three riders took no evasive action and roughly 40% of those who braked lost control and slid out or high-sided. This was true of trained, experienced police riders as well as riders with only informal training or no training at all. That is, at least for accident-involved riders, evasive action skills seemed to disappear in the few seconds just before impact. This paper goes further to suggest that skilled braking improves the odds of avoiding serious injury somewhat but cannot assure the individual rider of a better outcome.

Given the many limitations of emergency evasive action riders should understand that their first line of defense – alert, actively defensive riding aimed at preventing car drivers from initiating that fateful maneuver likely to lead to a crash, or aimed at blundering into a solo crash situation – is by far the best assurance of arriving safely at the intended destination.

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