Motorcycle Helmet Effect on a Per-Crash Basis in the Thailand and Hurt Studies

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Abstract

The data reported here are drawn from two detailed, in-depth studies of motorcycle accidents in which trained investigators collected extensive evidence on-scene immediately after the crash. This paper compares helmeted and unhelmeted motorcycle riders on a per-accident basis for fatality rates, for the frequency of serious (AIS>2) brain injuries among survivors or for what is referred to here a “disastrous outcome” involving either one of the two results. Nine hundred motorcycle crashes in Los Angeles and 969 crashes in Thailand involving 1,082 riders were investigated in detail at the accident scene, including photos of vehicles, skids, damage and sometimes the rider. Helmets were collected and injury information was obtained from riders and care providers. This evidence was then used to reconstruct collision events to identify speeds, precrash motions, collision contacts, injury causation and helmet performance. In both studies, approximately 20-25% of riders were hospitalized and about 6% were killed. Overall, unhelmeted riders were 2-3 times as likely to be killed, and three times as likely to suffer a “disastrous outcome.” Unhelmeted survivors had 3-4 times as many AIS>2 brain injuries as helmeted riders on a per-crash basis. Unhelmeted riders consistently fared worse than helmeted riders, even when alcohol use was taken into account. Nearly 100% of riders with AIS>4 injuries below the neck died. Crashes that produce such critical injuries are therefore considered to be nearly unsurvivable, regardless of helmet use. Such extreme crashes were 30% of the 63 fatalities in Thailand and 57% of the 54 deaths in Los Angeles, but only about 2-3% of the overall accident population but were. Among the other 97% of riders, universal helmet use could prevent about 80% of fatalities and brain injuries. Helmet use cannot prevent all fatalities because many riders die as the result of below-the-neck injuries that a helmet cannot prevent, but it is extremely effective in preventing death and serious brain injury among riders with survivable below-the-neck injuries.

KEYWORDS Motorcycle, helmet, brain injury, alcohol, fatality, Thailand, Hurt

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1. INTRODUCTION

Motorcycle helmet effectiveness has been studied in a variety of ways. Perhaps the most common method has been to study motorcyclist fatality rates before and after a change in mandatory helmet use laws (Dare et al., 1979; Chenier and Evans, 1987; Kraus et al., 1994; Panichabhongse et al., 1995; Peek-Asa & Kraus, 1997; Preusser et al., 2000; Branas & Knudson, 2001; Auman et al, 2002; Bledsoe et al., 2002; Muller, 2004; Ulmer & Northrup, 2005; Turner & Haegelin, 2005). These studies typically have reported that fatalities declined after a mandatory helmet law applicable to all riders went into effect or that fatalities increased after the law was repealed or eviscerated (by exempting all but the youngest riders from the requirement to wear a helmet.)

Other studies have compared helmeted and unhelmeted samples of hospitalized riders (Gabella et al, 1993; Offner et al., 1992; Rutledge & Stutts, 1993), sometimes matching them to police reports (Peek-Asa & Kraus, 1997). They have usually reported higher fatality rates, longer hospitalizations and higher treatment costs for unhelmeted riders. Still others have compared riders and passengers on the same motorcycle (Evans & Frick, 1987; Anderson & Kraus, 1996; Norvell & Cummings, 2002), on the assumption that both are subjected to the same collision forces. Lawrence et al. (2002) reviewed 25 helmet studies, most from the 1990's, that compared helmet use and medical costs in motorcycle accidents and reported that helmets reduce fatalities, the frequency and severity of brain injuries, long-term disability and medical costs.

The underlying data for most of these studies comes from police reports and/or medical records. The little information about the crash usually comes only from the police report, which may suffer from limited and perhaps inaccurate information about accident events, since few police officers have any training in motorcycle accident investigation or reconstruction. On the other hand, studies that examine only the minority of the accident-involved motorcyclists admitted to a hospital or fatalities usually fail to address whether their sample reflects helmet use in the larger accident population. It is perfectly reasonable to think that unhelmeted riders might be hospitalized more often (or less often) than helmeted riders, but hospital-based studies do not address this issue.

Helmet type is rarely identified in most studies. This is particularly problematic if the helmet is the close-fitting "beanie" or "novelty" variety that lacks an energy-absorbing liner. Novelty helmets have virtually no protective capability – other than perhaps preventing sunburn (Southwest Research Institute, 1992; United States Testing Co., 1992a, 1992b, 1993; Peek-Asa et al., 1999). Helmets that meet a recognized standard such as the DOT standard (FMVSS 218) can provide excellent protection when tested at drop heights of 12 feet (3.66 m) or more, but novelty helmets are likely to "bottom out" at drop heights less than 18 inches (46 cm). The two helmet types are shown in Figure 1. When data from riders wearing ineffective head coverage are combined in a sample with riders wearing a helmet designed to meet some widely recognized standard such as the DOT standard, the inevitable result is to obscure the apparent effectiveness of truly protective headgear.

The data reported here come from two separate studies in which motorcycle accidents were investigated in detail by specially trained investigators who were on the scene immediately after the crash occurred – often while the rider was still present. Helmets were obtained for examination and analysis, which was matched with collision evidence and rider injury information.

One study in Thailand in 1999-2000 (Kasantikul, 2002a, 2002b) involved 1082 riders, while the other (Hurt et al., 1981) was conducted in Los Angeles by researchers from the University of Southern California in 1976-77 and involved 900 riders. Both studies used the essentially the same methodology to collect and analyze the evidence obtained during the on-scene investigation (including the helmet). The evidence was then used to reconstruct the collision events and identify accident and injury causation factors and to evaluate helmet performance. This allows comparison of helmet effectiveness even though the two studies are separated by nearly 25 years and differences in helmets, motorcycles and even traffic environments.

2. METHODS

In both study areas, teams of specially trained investigators traveled to an accident scene immediately after the crash in order to conduct a detailed research investigation and analysis independent of the police investigation. 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 both studies, injury information was obtained from medical care providers and from riders themselves. 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 accident and injury causation and evaluate helmet performance.

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, which is why there were more motorcycles than collisions.) The USC study involved 900 riders and 154 passengers in the City of Los Angeles. Passenger data are not included in the analysis here.

2.1 Helmet Use

Helmet use and ejection were determined by a variety of means that included examination and disassembly of the helmet to identify and measure collision damage, as well as rider, passenger and eyewitness interview statements. The cause and timing of helmet ejection was determined wherever possible. In Los Angeles, only about 5% of helmets came off during the crash, usually because the rider failed to fasten the chin straps. This percentage was so low that all helmeted riders in Los Angeles are treated as “helmeted,” whether the helmet ejected or not. In Thailand, however, nearly one-fourth of helmets came off (again, usually due to poor fit or failure to fasten the retention system properly), so these ejection cases are considered separately from helmet-retained cases.

2.2 Brain Injury Coding

The “head injuries” reported in this study are specifically intracranial injuries. If a rider had rider had superficial bruises, lacerations or abrasions around his face or head, but no evidence of neurological injury, he was coded as having no brain injury for our purposes. The Thailand injury data were coded using the 1990 version of *The Abbreviated Injury Scale* (Committee on Injury Scaling, 1990). The brain injuries reported in this paper included the following AIS-90 codes: crush (11300.6), intracranial blood vessel injuries (12099.3 – 122806.3), brain and meningeal injuries (140299.5 – 140799.3), skull injuries (150200.3 – 150408.4) and loss of consciousness (160202.2 – 161000.2).

The Los Angeles head injury data was coded using a 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. Injury severity in the USC data set was coded in accordance with the 1980 revision of *The Abbreviated Injury Scale* (Committee on Injury Scaling, 1980). The use of two different versions of the Abbreviated Injury Scale should not be a problem because the statistical comparisons are made within each database, not across databases. Also, brain injury severity classifications are very consistent between the two versions.

Some examples of minor to moderate (AIS 1-2) brain injuries include simple linear skull fractures, unconsciousness less than one hour without neurological deficit or post-crash headache or dizziness or amnesia for accident events but with no loss of consciousness. Examples of brain injuries in the serious to fatal range (AIS 2-6) include basal skull fractures, loss of consciousness for more than one hour or with any lingering neurological deficit, bleeding in the subarachnoid or subdural spaces between the skull and brain, contusions on the surface of the brain or bleeding within the brain, brainstem injuries, diffuse axonal injury or crush or decapitation injuries. The AIS>2 brain injury severity level among surviving riders is chosen because Ross et al. (1992) found markedly worse functional outcomes for riders who survived with a brain injury AIS>2.

2.3 Comparisons

It is easy to tally fatality rates or brain injury rates among survivors, since they are mutually exclusive categories. However, some care must be taken when combining the two categories to avoid counting a rider twice, once if he was fatally injured and again if he suffered a brain injury. Therefore the category labeled “disastrous outcome” divides riders into two groups: 1) those who were either fatally injured or who survived but suffered AIS>2 brain injury and, 2) those who met neither of those criteria.

A chi-square statistical test was used for most of the analyses reported here. If the expected cell frequency was less than 5, the results of a Fisher Exact Test are reported. The probabilities reported here are for a two-tailed test. Probabilities less than .05 were considered to be significant.

3. RESULTS

Helmet use was known for all but nine of the 1,982 riders (99.5%) in the two studies. Forty percent of riders in Los Angeles (355 of 892) wore a helmet. In Thailand, about half the riders wore a helmet: 420 of 1081 riders (39%) retained the helmet through the entire crash sequence, while 133 (12%) wore a helmet that ejected before the rider reached the point of rest, and 528 riders (49%) failed to wear a helmet at all when they crashed.

3.1 Fatality Rates

In Los Angeles, unhelmeted riders were more than twice as likely to be killed as helmeted riders on a per-accident basis (7.6% vs. 3.4%) and the difference was statistically significant ($\chi^2 = 6.92$, $p = .008$, $df = 1$). Helmeted riders were 40% of the accident sample but only 23% of the fatalities.

In Thailand, unhelmeted riders were more than three times as likely to be killed, and helmet-ejected riders were more than six times as likely to be killed as riders whose helmet stayed on. That is, only 1.9% of the helmet-retained riders, compared to 6.8% of the unhelmeted riders died and 12.8% of helmet-ejected riders. The difference among the three groups was statistically significant ($\chi^2 = 25.05$, $p < .001$, $df = 2$) and all three pair-wise comparisons were significantly different ($\chi^2 > 5$, $p < .02$, $df = 1$).

3.2 Brain Injury Frequency in Survivors

In Los Angeles, a total of 94 of the 839 riders who survived (11%) suffered some level of brain injury (AIS 1-5), and 29 riders (3.5%) had a brain injury in the AIS 3-5 (serious-to-critical) range. However, brain injury rates differed as a function of helmet use. Unhelmeted surviving riders suffered a brain injury at any level of severity (AIS 1-5) nearly 60% more often than helmeted riders (13.5% vs. 7.9%) – a difference that was statistically significant ($\chi^2 = 6.5$, $p = .011$, $df =1$). Unhelmeted riders were also three times as likely (4.8% vs. 1.5%) to suffer a major brain injury (AIS 3-5). Comparisons of brain injury rates among surviving riders are shown in Table 1.

Table 1. Brain injury rates among survivors in Los Angeles & Thailand.

Los Angeles - Brain injury rates among surviving riders							
Comparison	No helmet (N = 496)		Helmet retained (N = 343)		χ^2	p	df
	n	%	n	%			
Brain AIS 1-5	67	13.5	27	7.9	6.48	.011	1
Brain AIS 3-5	24	4.8	5	1.5	6.95	.008	1

Thailand - Brain injury rates among surviving riders									
Comparison	No helmet (N = 492)		Helmet retained (N = 411)		Helmet ejected (N = 116)		χ^2	p	df
	n	%	n	%	n	%			
Brain AIS 1-5	57	11.6	8	1.9	30	25.9	66.97	.001	2
Brain AIS 3-5	10	2.0	2	0.5	3	2.6	4.81	.090	2

Among the 1019 Thai riders who survived, unhelmeted riders were nearly six times as likely as helmet-retained riders (11.6% vs. 1.9%) to suffer a brain injury at any level of severity (AIS 1-5). Helmet-ejected riders who survived fared even worse, with 26% sustaining some kind of brain injury. The differences were statistically significant, and all three pair-wise comparisons differed significantly ($\chi^2 > 15.6$, $p < .0001$, df =1). Only two of the 411 helmet-retained surviving riders (0.5%) suffered AIS 3-5 brain injury, compared to 2.0% of 492 unhelmeted survivors and 2.6% of survivors whose helmet ejected. Although the overall difference in the frequency of AIS 3-5 brain injuries was not significantly different (p = .09), helmet-retained survivors had significantly fewer AIS 3-5 brain injuries than unhelmeted riders ($\chi^2 = 4.08$, p = .043, df = 1). Comparisons involving helmet-ejected riders were not statistically significant.

3.3 "Disastrous outcome" – Death or survival with serious brain injury

On a per-accident basis in Los Angeles, the 537 unhelmeted riders were about 2.5 times as likely as the 355 helmeted riders (12.1% vs. 4.8%) to suffer the "disastrous outcome of either death or AIS>2 brain injury if they survived the crash. Helmeted riders were 40% of the sample but were only about 20% of those with a "disastrous outcome." The difference was statistically significant ($\chi^2 = 13.70$, p = .0002, df = 1).

The Thailand data were similar. Unhelmeted riders were more than 3.5 times as likely as helmeted riders to either die or to sustain AIS>2 brain injury if they survived survive with: 2.4% of helmet-retained riders, compared to 8.7% of unhelmeted riders and 15%

of helmet-ejected riders. The overall comparison was statistically significant (χ^2 = 29.22, $p < .0001$, df = 2), as were all three pair-wise comparisons ($\chi^2 > 4.7$, $p < .03$, df = 1).

3.4 Helmet and alcohol effects

Both alcohol use and failure to wear a helmet are often correlated with each other and with higher rates of head injury and death, as well as with particular accident characteristics (Ouellet et al., 1987; Kasantikul et al., 2005; Nakahara et al., 2005; Sauter et al., 2005.) Therefore, the question can arise whether the higher rates of brain injury and death among unhelmeted riders are the result of failure to wear a helmet or the result of alcohol use and characteristics of alcohol crashes (such as single vehicle, loss-of-control crashes, often involving running off the road at night.) Tables 2 and 3 attempt to untangle this issue by examining drinking riders (Table 2) separately from drinking riders (Table 3.) In Los Angeles, about 12% of all riders and half the fatally injured riders had been drinking before they crashed. In Thailand, 36% of all riders (and 75% of fatally injured riders) had been drinking before they crashed.

Table 2 compares non-drinking riders in Los Angeles and Thailand. (In Thailand, “helmeted” riders refers only those riders whose helmet remained on their head to the end of the accident sequence.) Non-drinking riders in Los Angeles who failed to wear a helmet were more than twice as likely to be killed, to suffer a serious brain injury if they survived or to suffer a “disastrous outcome” and the differences were statistically significant. In Thailand, unhelmeted non-drinkers were more than twice as likely to be killed, more than six times as likely to suffer a serious brain injury if they survived and more than three times as likely to suffer as “disastrous outcome,” but only the difference in “disastrous outcome” was statistically significant, largely because such injuries were generally less common among non-drinkers in Thailand than in Los Angeles.

Table 2. Injury outcome as a function of helmet use among non-drinking riders in Los Angeles (L.A.) and Thailand.

Non-drinking riders	Unhelmeted		Helmeted		Statistics	
	n / N	%	n / N	%	χ^2	p
L.A. – Fatal	21 / 439	4.8%	7 / 331	2.1%	3.84	.05
L.A. – Survived BAIS>2	17 / 418	4.1%	5 / 324	1.5%	4.04	.04
L.A. – “disastrous outcome”	38 / 439	8.7%	12 / 331	3.6%	7.87	.005
Thailand – Fatal	8 / 322	2.5%	3 / 295	1.0%	1.89	.17
Thailand – Survived BAIS>2	7 / 314	2.2%	1 / 292	0.3%	FET*	.07
Thai – “disastrous outcome”	15 / 322	4.7%	4 / 295	1.4%	5.63	.018

* FET = Fisher’s Exact Test used because some expected frequencies were less than 5.

Table 3 compares alcohol-involved riders in Los Angeles and Thailand. Drinking riders in Los Angeles who failed to wear a helmet consistently fared worse than drinking riders who wore a helmet, but the differences fell short of statistical significance, partly because there were too few drinkers, particularly helmeted drinkers. For example, about 39% of the 900 riders (355) wore a helmet and 12% of all riders had been drinking. Based on these proportions, one would expect about 42 helmeted drinkers, twice as many as the 20 who were actually seen. Unhelmeted drinkers in Los Angeles were 1.5 times as likely to die in a crash, twice as likely to suffer a “disastrous outcome” in a crash, and far more likely to have a serious brain injury if they survived (9% vs. 0%) compared to helmeted riders.

The large number of drinking riders in Thailand also shows that unhelmeted drinkers were four times as likely to be killed and 3.5 times as likely to suffer a “disastrous outcome” as helmeted riders, and the differences this time were statistically significant. As in Los Angeles, unhelmeted drinkers in Thailand were more likely to suffer serious brain injury if they survived, but once again the differences were not statistically significant.

Table 3 Injury outcome as a function of helmet use among alcohol-involved riders in Los Angeles (L.A.) and Thailand.

Drinking riders	Unhelmeted		Helmeted		Statistics	
	n / N	%	n / N	%	χ^2	p
L.A. – Fatal	19 / 83	22.9%	3 / 20	15%	FET	.554
L.A. – Survived, BAIS>2	6 / 64	9.4%	0 / 17	0%	FET	.334
L.A. – “disastrous outcome”	25 / 83	30.1%	3 / 20	15%	1.86	.172
Thailand – Fatal	27 / 203	13.3%	4 / 123	3.3%	9.00	.003
Thailand – Survived, BAIS>2	2 / 176	1.1%	1 / 119	0.8%	FET	.644
Thai – “disastrous outcome”	29 / 203	14.3%	5 / 123	4.1%	8.56	.003

3.5 Projected Outcomes

One way to elucidate the effect of helmet use is to project the outcome if either all of the riders or none of them had worn a helmet, compared to the 40% helmet use rate seen in these studies. The projected outcome can be estimated by applying to all riders the outcome rate of helmeted riders or the outcome rate of unhelmeted riders.

However, some caution is needed in calculations involving helmet effect on fatalities because a sizeable percentage of fatally injured riders have such severe somatic (below-the-neck) injuries that they would have died whether they wore a helmet or not. In Thailand, 20 of 21 riders with AIS 5-6 somatic injuries died; they were 1.9% of the 1082 cases, but about one-third of the 62 fatalities. In Los Angeles, all 31 riders with AIS 5-6 somatic injuries died. They were 3.3% of all 900 cases and 57% of the 54 fatalities.

Therefore, the projected outcomes shown in Table 4 are calculated only for riders with AIS<5 somatic injuries, on the assumption that helmet use cannot prevent death when injuries below the neck – which are not affected by helmet use – are in the AIS 5-6 range. Calculations of the Thailand data exclude helmet-ejected riders because of their ambiguous status as neither quite helmeted nor entirely unhelmeted.

Table 4: Actual outcome compared to predicted outcomes if 100% or 0% of riders with less-than-critical injuries (AIS<5) below the neck had worn a helmet. The column labeled "Δ" represents the reduction or increase in frequency relative to the actual outcome.

Comparison	Study	N (MAIS<5)	Projected outcome if 100% wore a helmet			Actual outcome (40% helmet use)		Projected outcome if 0% wore a helmet		
			%	n	Δ	%	n	%	n	Δ
Fatality rates	L.A.	862	0.9	7	-16	2.7	23	3.9	33	+10
	Thai	935	1.0	9	-24	3.5	33	5.6	52	+19
Survivors, Brain AIS 3-5 rates	L.A.	839	1.5	12	-17	3.5	29	4.8	41	+12
	Thai	902	0.5	4	-8	1.3	12	2.0	18	+6
Fatal or survived with Brain AIS>2	L.A.	862	2.3	20	-32	6.0	52	8.5	74	+22
	Thai	936	1.4	14	-31	4.8	45	7.5	70	+25

Table 4 shows that in both Thailand and Los Angeles (L.A.), if 100% of riders had worn a helmet (instead of the approximately 40% actual use rate), it would have reduced the frequency of fatalities by approximately 70%, reduced the number of riders who survived with AIS>2 brain injury by about 60%, and reduced the number of riders who met either of those two criteria by 60-70%. Conversely, if none of the riders wore a helmet, the result consistently would have been about 50% more deaths, 40-50% more AIS>2 brain injuries among those who survived and 50% more riders who suffered one or the other of those "disastrous outcomes."

If the two projected outcomes in Table 4 – for 100% helmet use and 0% helmet use – are compared, unhelmeted riders were about five times as likely as helmeted riders to die, about four times as likely to suffer AIS>2 brain injury if they survived their crash, four to five times as likely to suffer a one or the other of those outcomes. The comparisons were all statistically significant ($\chi^2 > 4.07$, $p < .045$, df = 1), and all but one were significant beyond the .01 level.

4. DISCUSSION

The findings that stand out in this study are: 1) unhelmeted riders were 2-3 times as likely to be killed as helmeted riders; 2) unhelmeted survivors were about 3-4 times as likely to suffer a potentially debilitating (AIS>2) brain injury, 3) unhelmeted riders were about two to four times as likely to suffer either of those two adverse outcomes of death or survival but with AIS>2 brain injury as helmeted riders on a per-accident basis and, 4) these effects persist even when the effects of alcohol use are taken into account.

The benefit of helmet use is even more clear when one eliminates the riders who were in crashes so severe as to be virtually unsurvivable whether they wore a helmet or not. In both studies, nearly 100% of riders with AIS>4 below-the-neck injuries died. Fifty-seven percent of fatalities in Los Angeles and 30% in Thailand had AIS 5-6 below-the-neck injuries. It should be apparent that universal helmet use cannot eliminate all motorcycle fatalities because extreme crashes with AIS>4 somatic injuries are likely to be about 2-3% of any accident population. However, among the 97% of riders in less-than-extreme crashes, helmet use can prevent approximately three-fourths of serious brain injuries and deaths.

Hurt & Thom (1992, 1994) have detailed the mechanics of how helmets work to prevent brain injuries, while Newman (1980) has identified some of the situations in which helmet use simply cannot prevent brain injury. Previous estimates of helmet effectiveness by the National Highway Traffic Safety Administration (NHTSA) have estimated that helmets reduce fatalities by 29% (Wilson, 1989), a figure later revised to 34% (Deutermann, 2004). However, the estimates by NHTSA included all fatally injured riders, regardless of somatic injury severity – that is, NHTSA included riders whether a helmet could have prevented the rider's death or not.

Current helmets in the U.S. and Europe may be even more effective than those reported here because of better helmet construction, particularly thicker energy-absorbing liners, which provide the additional stopping distance that helps prevent excessive brain acceleration. Liners in current helmets are often 25-35 mm thick, compared to the 20-25 mm commonly seen in Los Angeles and even thinner in Thai helmets.

Many motorcyclists say they would rather be killed than survive a crash as a brain-injured "vegetable." The reasoning is that crashing without a helmet means death, while crashing with a helmet on means survival, but at the cost of a devastating brain injury. Thus it may seem to be a logical choice to ride without a helmet. The findings reported here make it clear that unhelmeted riders invite the worst of both worlds. Riding without a qualified helmet securely fastened on the head doubles or triples the rider's risk of death, and triples the risk of a debilitating brain injury if the rider survives the crash. There can be no mistaking the message that comes from the experience of nearly 2,000 riders whose crashes have been studied in great detail: No rider should get on a motorcycle without a qualified helmet securely fastened on his or her head.

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