The Dynamics of Motorcycle Crashes

Focus on Advanced (Antilock) Braking Systems and Post-crash Motion

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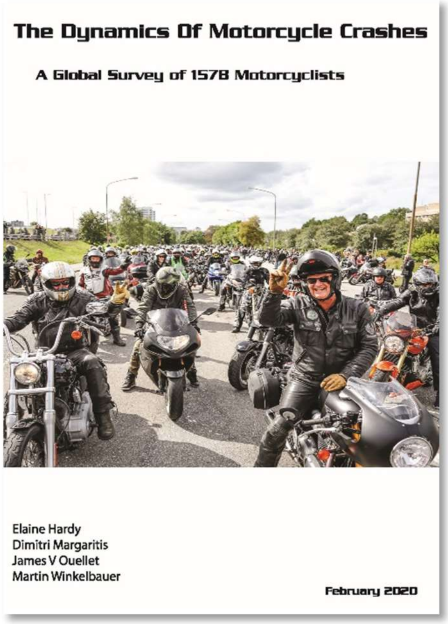

Abstract

An online survey was carried out in 2019 which focused on motorcyclists who had been involved in a crash. The survey was disseminated throughout Europe, the USA, Canada, Asia, Australia and South America in order to get as much of a global response as possible.

The study extends and expands a pilot study based on a survey of motorcyclists whose motorcycles were fitted with the technology of Advanced (Antilock) Braking Systems (ABS), which was carried out in 2016/2017.

Because this study involved riders responding to an online survey, an important element is that the data involve their perspective of how a crash occurred rather than that of academic research. They also provided information about injuries and long term recovery that is usually not a part of on-scene, in-depth studies.

A sample of 1,578 motorcycle riders from 30 different countries answered a questionnaire which included 39 questions on much more than the typical parameters of crashes.

Particular focus was put on questions most relevant to motorcycles like the use of protective equipment and assistance systems, in particular ABS.

Many interviewees provided comments throughout the questionnaire and 832 provided further descriptions of their crashes, which allows deep insight to the dynamics of crashes and their circumstances, which would not be captured in a usual survey.

The survey's overall results highlight the relationship between speed, protective equipment, assistance systems and injuries, as well as how post-crash motions change the patterns of crash occurrence and injury outcome.

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1. Introduction

The relevance and importance of Advanced (Antilock) Braking Systems (ABS) has been at the centre of debates for motorcycle safety researchers, governments and industry even more so as the European Commission considers mandating ABS on smaller motorcycles (i.e. 51-125cc). This paper aims to take a closer look at the outcome of crashes in particular for ABS-equipped motorcycles in relation to the post-crash motion of the rider and the eventual outcome in terms of injuries.

ABS are expected to improve collision avoidance by assuring that both front and rear brakes are applied and to reduce the possibility of riders falling or sliding in an emergency situation. However, what has been highlighted in this study is that over a third of the riders did not use their brakes, whether they just did not have time or were unable to because of the circumstances. In a similar way, the on-scene, in-depth Hurt and Thailand studies reported high levels of failure to take collision avoidance action: 32% in the Hurt study[1] and 49% in Thailand (Ouellet and Kasantikul 2006)[2].

However what differs in this study from the two studies mentioned above, is that over the last 20 years, motorcycles have developed and modernised such that technology is an integral part of how the machine operates. How the ability to brake or not can be addressed is relevant to the fact that in this study one third of the motorcycles were equipped with ABS. Does technology matter in a crash scenario? Consider that the time between the event that leads to the crash and the impact rarely exceeds 3-4 seconds (Ouellet and Kasantikul, 2006)[3] while rider perception/reaction time – typically 0.75 – 1.5 seconds[4] consumes a sizable portion of the time available for collision avoidance. The assumption that technology will save the day, may miss the obvious fact that what matters in an emergency situation is the rider him/herself and his/her ability to control the technology.

Over a third (36.3%) of the respondents of the survey had ABS brakes fitted to their motorcycles, while 12% had traction control fitted with 6.4% reported having cornering ABS fitted. What is not known is whether this sample is representative of larger population of motorcycles on the road.

Included in this paper in Annex one, is a profile of six motorcyclists and their motorcycles which were fitted with ABS. In each case the riders describe the circumstances of the event and their injuries.

2. Methodology

2.1 Survey

In order to have a more valid understanding of the dynamics of motorcycle crashes, this study extends and expands a previous pilot survey and covers eight different languages: English, French, Swedish, German, Spanish, Italian, Greek and Norwegian.

This survey took place between May and October 2019 and was disseminated through magazines, Facebook, motorcycle forums and web sites. The wealth and depth of information provided by the motorcyclists who participated allowed for a wide range of analysis of the details that resulted from the questionnaire and the responses.

The questionnaire had 39 questions divided into four sections:

1. “About you and your motorcycle” (16 questions)
2. “Background” (11 questions)
3. “Crash Details” (11 questions)
4. “Further Comments” (this allows plenty of space for the rider to comment freely)

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[1] Hurt, HH, Jr., Ouellet, JV and Thom, DR, *Motorcycle Accident Cause Factors and Identification of Countermeasures, Final Report*, DOT-HS-F-01160, 1981, p.49.

[2] Ouellet JV and Kasantikul V; (2006); Rider training and collision avoidance in Thailand and Los Angeles motorcycle crashes; *Proceedings, International Motorcycle Safety Conference,* Motorcycle Safety Foundation, Irvine, CA, 2006

[3] Ouellet JV, How the timing of motorcycle accident investigation affects sampling and data outcome; *Proceedings, International Motorcycle Safety Conference,* Motorcycle Safety Foundation, Irvine, CA, 2006.

[4] Forensic Aspects of Driver Perception and Response, Paul Olsen, Lawyers and Judges Publishing Company Inc. 1996. ISBN 0-913875-22-8

2.2 Sample characteristics and Data analysis

The motorcyclists participating in the survey came from 30 countries throughout the world. In total 1,578 motorcyclists replied to the survey. Due to the dissemination of the survey through organisations, clubs, social media and websites typically frequented by motorcyclists, it suggests that the rider is more inclined to be a "life-style" motorcyclist. However, this is a sample of people who have crashed irrespective of where they came from or their motivation for riding a motorcycle.

Analysis of factors such as seasons depending on whether the rider came from the southern or northern hemisphere and whether the distance was measured in kilometres or miles were taken into account.

Data analysis was carried out using Excel and SPSS. Pearson Chi-Square test of independence was used to discover if there was a relationship between two categorical variables in the cross-tabulation tables. Also analysed were the comments left by the respondents, of whom 832 left further comments detailing the events surrounding their crash.

3. Accident scenario

3.1 Collision characteristics

When

These crashes were distributed somewhat evenly around the week, with Saturday over-represented (20%) and Monday underrepresented (9.5%). About three-fourths occurred between 8 a.m. and 6 p.m. Only 6% occurred between 8 p.m. and 5 a.m. Not surprisingly, far fewer crashes occurred in winter (11%) than summer (36%).

Where

Eighty-four percent of riders reported living in EU countries (including the UK), 6% in the USA-Canada, and 8% in Australia. Of n. 1446 riders who gave an answer about the type of road where they crashed, n.657 (45%) said they crashed on a straight segment of roadway, 14.5% on a curve to the left, 14% on a curve to the right and 8% (n.120) at a roundabout.

Nearly one-third of the respondents reported that the road surface had some kind of problem. Of the minority of road surfaces that presented control problems, loose gravel or dirt accounted for 24% of those problems and water another 24%. Lubricants such as oil or diesel accounted for another 15% of the surface contaminants.

Who

Ninety-one percent of the respondents were male; the median age was 44 and the largest age group was in the 45-54 age range. Eighty-six percent held a full licence. Only one in 40 (2.5%) said they had been riding less than a year while five percent said they had been riding over 40 years consecutively. The median riding experience was about 14 years with 8 consecutive years of riding before their crash. Only about 7% were carrying a passenger when they crashed.

Forty-three percent of riders (n.684) said they had taken a voluntary post-licence rider safety course, for a total of nearly 3,300 courses or an average of five per rider. Overall, n.314 said they had taken a course in emergency braking with ABS (about 55% of the n.573 who said their motorcycle was equipped with ABS).

The type of licence held by the riders at the time of the crash indicated that 85.4% (n.1347) held a full licence (A in Europe) while 5.5% (n.87) held an A2 licence (in Europe) or provisional licence and 2.8% (n.44) held an A1 licence (in Europe).

The motorcycles

Table 1 shows some of the motorcycle types that accounted for about 90% of the total. Scooters and mopeds combined made up about another 5%. In terms of style and injuries, this reflects the overall proportion of motorcycles that were ridden by the respondents, equally, the highest proportion of injuries of the riders are indicated as Naked (30%) followed by Adventure (15.9%) then Supersport (14.6%) with injuries[5].

Table 1

Style	Frequency	Percent
Naked (Streetbike)	484	30.7
Adventure	251	15.9
Supersport	232	14.7
Sports Tourer	168	10.6
Touring	118	7.5
Cruiser	87	5.5
Custom	84	5.3
Total	**1424**	**90.2**

The distribution of motorcycle engine size is shown in Table 2. Fifty-seven percent fell into the 500-1000 cc range and another 28% were larger than 1000cc. Motorcycles under 500cc were only 15% of the total. This distribution (as well as the information provided regarding country of residence) reflects the fact that the great majority of respondents were from developed nations.

Table 2

	Frequency	Percent	Valid Percent
Up to 50cc	16	1	1.0
51cc to 125cc	66	4.2	4.2
126cc to 250cc	59	3.7	3.8
251cc to 500cc	91	5.8	5.8
501cc to 750cc	499	31.6	31.8
751cc to 1000cc	389	24.7	24.8
>1000cc	448	28.4	28.6
No Answer	10	0.6	-
Total	**1578**	**100**	**100**

As noted earlier, 36% of riders (n.573) indicated that their motorcycle was equipped with ABS, 12% (n.190) with traction control and 6.4% (n.101) with cornering ABS.

Table 3

	Frequency	Percent
Antilock brakes (ABS)	573	36.3
Traction Control	190	12
Cornering ABS	101	6.4

3.2 Motorcycle pre-crash speed

Based on the findings of previous motorcycle crash investigations (Hurt and Thailand studies), riders typically have a reasonable estimate of how fast they were going before the situation turned ugly yet no clear idea of their speed when they actually crashed. We asked riders to estimate their speed within a 10 km/hr range and assumed they were giving us the pre-crash speed. Figure 1 shows a cumulative percent distribution of the estimates given by 1,413 riders (150 estimated in miles per hour, while 15 gave no answer.) The median speed fell in the 31-40 km/hr range (19-25 mph) while the 90th percentile speed was around 80 km/hr (50 mph).

[5] See table 62 of the report "Dynamics of Motorcycle Crashes".

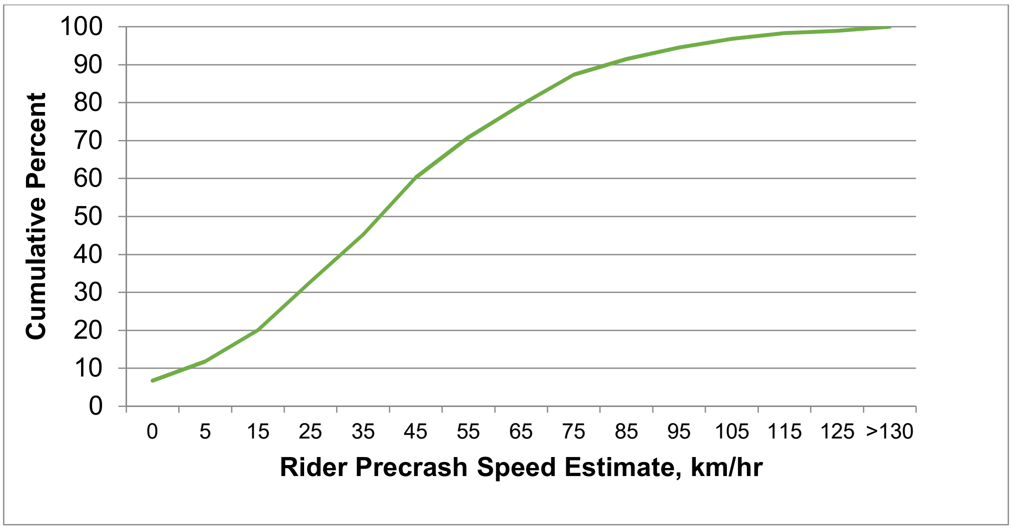

Figure 1 Cumulative percent distribution of estimated speed

3.3 Speed, days in hospital and rehabilitation - comments by riders

How speed effects the severity of injuries is a major focus of debate amongst road safety analysts. The following table 4 identifies estimated speed, days in hospital, days in rehabilitation post-crash and the type of injuries of n.33 respondents of the n.45 respondents who spent more than n.20 days in hospital.

The rider who was stationary when hit, spent 90 days in hospital (possibly due to the speed of the vehicle who crashed into the rider) and 120 days in rehabilitation while the rider whose speed was above 130 kph spent 51 days in hospital and further 120 days in rehabilitation[6].

Table 4

Estimated Speed	Comments injuries	Days in hospital	Days rehab.
Stationary	Damage to left lung	90	120
1 to 10 kph	Lost consciousness – severe lower limb injuries	45	300
1 to 10 kph	The rear footrest bore into the calf above the boot and slit the calf open.	20	
21 to 30 kph	Left leg	20	180
31 to 40 kph	Lost a lot of hearing on both ears. Almost deaf on the left. Wearing hearing aids today	90	30
31 to 40 kph	Broken humerus left side. Muscle pains in shoulder and lowerback	38	
31 to 40 kph	Leg amputated (Right leg was cut off in the middle of the thigh on a sharp-edged guardrail post.	28	120
31 to 40 kph	Complicated fracture ankle, shin and fibula	20	90
31 to 40 mph	Damage to Lungs and Spleen.	60	150
41 to 50 kph	Spinal cord infarction leading to lower paralysis and three years in a wheelchair.	72	110
41 to 50 kph	The bone was twisted, doctors said it was the most severe knee injury they had seen in 15 years. They were thinking of amputating first, could not walk again. Prosthesis was surgical after MANY trips for 3.5 years. Wheelchair bound for 2.5 years.	30	720
41 to 50 mph	There were indications of spine damage on the initial CT scan, however I have not had any back problems since then.	35	365
41 to 50 mph	Collapsed lung , haemothorax, pneumothorax, bruised kidneys, broken & bruised thumb & fingers	20	
51 to 60 kph	Fracture of the right internal malleolus, open fracture of the right femur, three cracked ribs on the right, a pneumothorax. Fracture of the right clavicle, open fracture of the radius and ulna and slight head trauma.	158	1000
51 to 60 kph	Fracture of the right tibial plateau dislocation of the left shoulder	150	180
51 to 60 kph	Ribs, vertebra and teeth	40	

[6] Further details of the speed versus injuries correlation are found in Chapter 9 of the report "Dynamics of Motorcycle Crashes".

Table 4 continued

51 to 60 kph	Explosion of the acetabulum and lesion of the right sciatic nerve	25	60
51 to 60 kph	Lost most of my upper teeth, leg amputated after 25 operations over a 2 year period.	21	1500
51 to 60 kph	Punctured lung from broken ribs, fractures: 2 in neck, 1 in back, collarbone, shoulder, both shoulder blades, breastbone cracked, 22 rib fractures, minor nerve damage left leg (from slide)	20	90
51 to 60 kph	Fractured left leg and ankle broken in 7 pieces , Shoulder injuries split and separated main muscle. Still bad bloodflow and pain.	20	1000
51 to 60 mph	Fractured jaw	75	1000
51 to 60 mph	Spinal injuries	36	1200
61 to 70 kph	Pelvic fractures	60	180
61 to 70 kph	Small brain bleed. Broken wrist requiring surgery. Broken pelvis--no walking for eight weeks, three cuts to face.	39	39
71 to 80 kph	Wounds to the scrotum, Wounds to the knees, Detachment of the pleura, Fracture vertebra D2	150	600
71 to 80 kph	life threatening septicemia	56	200
71 to 80 kph	Broken collar bone, three broken ribs, broken pelvis front and back on both sides and a pneumothorax.	30	30
81 to 90 kph	Mental trauma which affects me for several years.	38	550
81 to 90 kph	Plexus brachial	22	600
81 to 90 kph	Held in coma for 5 days, 16 rib fractures, fractured vertebra, 2 folding lungs, torn lung, 8 litres of blood drained in, broken knee	21	365
81 to 90 kph	Fracture in the right hand and L5 vertebra	20	30
>130 kph	Hip fracture	51	120
> 130 kph	Broken Clavical (right) and 7 ribs (right)	30	

3.3 Speed and age of riders

Respondents who were travelling at a low speed of one to 10 kph prior to crashing, varied from 18 to 74 years with an average age of 46 years. Respondents who were travelling at speeds of between 91 to 100 kph varied from 17 years to 71 years with an average age of 42 years. Of the n.95 riders who were hit by another vehicle while stationary, the age varied from 17 years to 69 years, with an average age of 44 years. Of the n.15 respondents who indicated that they were travelling at >130 kph prior to crashing, the age varied from 22 years to 53 years and the average age was 39 years.

3.4 Braking prior to crash

Eight and a half percent of riders were uncertain or did not answer if they had braked or not. Of the 1,443 who answered either Yes or No (i.e. excluding uncertain or no answer), 38% said they had failed to apply the brakes. Table 5 highlights that over a third (35%) of the respondents did not use their brakes prior to crashing.

Table 5

Braking Action	Frequency	Percent
No	553	35.0
Yes	890	56.4
Uncertain/No Answer	135	8.5
Total	**1578**	**100**

3.5 Prior to crashing, did you apply the brakes?

Table 6

MC had ABS	Applied Brakes prior to crashing			
	No Answer/ Uncertain	No	Yes	Total
No	72	282	605	959
	53.3%	51.0%	68.0%	60.8%
Yes	56	259	258	573
	41.5%	46.8%	29.0%	36.3%
Uncertain /No Answer	7	12	27	46
	5.2%	2.1%	3.0%	2.9%
Total	**135**	**553**	**890**	**1578**
	100%	**100%**	**100%**	**100%**

Of the riders who had ABS-equipped motorcycles 45% (n.258) reported braking before they crashed, while 68% (n.605) of riders on a motorcycle without ABS reported using their brakes before the crash. The difference was highly significant (chi-square = 46.2, $p < .001$, df = 1) – and not easily explained.

Possibly more of interest is that of the n.553 who did not use their brakes prior to crashing, n.258 (46.6%) motorcycles had ABS brakes fitted, which raises the issue of perception/reaction time for the rider which is indicated at between 0.75 to 1.5 seconds by forensic crash scene investigators. In other words, the rider may not have had time to react[7]. A study on reaction times was carried out by Vavryn and Winkelbauer (1996) who found 2 peaks which were 0.18 seconds apart, suggesting that those with the finger on the brake lever were faster to react[8].

3.6 Separation from Motorcycle on Impact

Table 7

Separation from MC	Frequency	Percent
No	393	24.9
Yes	1135	71.9
No Answer	50	3.2
Total	**1578**	**100.0**

A quarter of the respondents (n.393) did not separate from their motorcycles on impact. Of these, n.95 of the riders were stationary when the crash occurred.

3.7 Trajectory or Post-crash Motion

Table 8

Trajectory	Frequency	Percent
Fell backwards	37	2.3
Highside and fell left	75	4.8
Highside and fell right	88	5.6
Left low-side - fell over to the left	313	19.8
Right low-side - fell over to the right	244	15.5
Topside, over the front of the handlebars	288	18.3
Other	106	6.7
Don't know/No Answer	427	27.0
Total	**1578**	**100**

[7]Forensic Aspects of Driver Perception and Response, Paul Olsen, Lawyers and Judges Publishing Company Inc. 1996. ISBN 0-913875-22-8

[8] Vavryn, K., & Winkelbauer, M. (1996). Bremsverzögerungswerte und Reaktionszeiten bei Motorradfahrern

The trajectory or post-crash motion of the riders (Table 8) indicates that the Left low-side with n.313 (19.8%) was the direction of the highest proportion of riders, followed by Topside, over the front of the handlebars, with n.288 (18.3%) and Right low-side with n.244 (15.5%).

3.8 Trajectory of rider after separation – Left Hand Traffic (LHT) and Right Hand Traffic (RHT)

The comparison with left hand traffic and right hand traffic in terms of trajectory (post-crash motion) is useful to understand whether riding on the left or the right side of the road has any bearing on the type of crash. The accepted view is that when crashes occur at bends in countries that drive on the left side of the road, the propensity to crash at a bend would be that the rider would go wide towards the right side of the road and head into oncoming traffic, conversely where a crash occurs in countries that drive on the right, the rider would go wide towards the left side of the road and head into oncoming traffic.

Table 9

Right Hand Traffic	Frequency	Percent
Highside and fell left	61	10.3
Highside and fell right	76	12.8
Left low-side - fell to the left	251	42.3
Right low-side - fell to the right	206	34.7
Total	**594**	**100**
Left Hand Traffic	**Frequency**	**Percent**
Highside and fell left	14	11.3
Highside and fell right	12	9.7
Left low-side - fell to the left	61	49.2
Right low-side - fell to the right	37	29.8
Total	**124**	**100**

LHT Countries Where Crash occurred: Australia, Guyane Française, Hong Kong, India, Nepal, New Zealand, South Africa, Thailand, UK.

RHT Countries Where Crash occurred: Austria, Belgium, Canada, Croatia, Denmark, Finland, France, Germany, Greece, Italy, Lithuania, Luxembourg, New Caledonia, Norway, Poland, Romania, Romania, Spain, Sweden, The Netherlands, USA

As table 9 above indicates, in this survey there appears to be little difference in the outcome of the trajectory whether riding in left hand traffic or right hand traffic when the rider fell Left low-side. Of those travelling on the right of the road n.251 (42.3%) indicated that their trajectory was Left low-side while n.61 (49.2%) of those travelling in left hand traffic indicated that their trajectory was also Left low-side – i.e. the majority of both groups indicated that they fell to the left. Could this be due to the fact that the front brake lever is on the right of the motorcycles? It is an interesting dilemma.

3.9 Where was the impact on the Motorcycle?

The biggest proportion of the position of impact on the motorcycle was frontal (15.4%) with 10.1% lateral left side and 12.4% lateral right side. This is followed by those motorcycles that were rear-ended (9%).

Table 10

Impact	Frequency	Percent
Frontal	243	15.4
Lateral - left side	160	10.1
Lateral - right side	195	12.4
Rear end	142	9.0
Other	50	3.2
Don't know/No Answer	788	49.9
Total	1578	100.0

The area of impact is indicated by the type of damage that the motorcycles sustained e.g. with the highest proportion on the handlebars (61.6%) and mirrors (66.2%), indicators (61.5%), front lights (38.3%) and front mudguard (36.6%). Other indicators are damage to the fairing, Screen, front forks and front wheel (Table 11). However, sooner or later, most of the motorcycles fall to the side, damaging handle bars, indicators, brake and clutch lever and the mirrors, thus the information is purely indicative.

3.10 What Damage Did the Motorcycle Sustain?

Table 11

Damage	Frequency	Percent
Mirrors	1045	66.2
Handlebars	972	61.6
Indicators	971	61.5
Fairing	927	58.7
Front Lights	605	38.3
Front Mudguard	578	36.6
Screen	562	35.6
Front Forks	552	35
Front Wheel	538	34.1
Tank	510	32.3
Gear Lever	508	32.2
Engine and Casing	468	29.7
Rear Brake Lever	437	27.7
Frame	399	25.3
Top Box & Panniers	386	24.5
Instruments	346	21.9
Other	332	21
Sub Frame	281	17.8
Brake Reservoir	219	13.9
Tail (Rear) Lights	207	13.1
Clutch Reservoir	197	12.5
Swing Arm	160	10.1
Back Wheel	155	9.8

3.11 Trajectory (Post-crash Motion)

Tables 12a, b and c identify the trajectory or post-crash motion of the motorcyclist when separated from the motorcycle.

The respondents whose trajectory was Left low-side indicated that a third (33.5%) had motorcycles with ABS brakes but did not use their brakes, while 26.2% (n.64) fell to the right (Right low-side) in both cases, just over half did not use their brakes prior to crashing.

Of particular interest is that 37.1% (n.107) of the n.288 respondents with ABS brakes on their motorcycles were projected Topside – i.e. over the front of the handlebars. This compares to 33.5% (n.105) left low-side and 26.2% (n.64) right low-side.

Table 12a

Trajectory		Did your motorcycle have ABS brakes		
	No Answer /Uncertain	Yes	No	Total
Fell backwards	1	21	15	37
	2.8%	3.7%	1.6%	2.3%
Highside and fell left	3	28	44	75
	6.5%	4.9%	4.6%	4.8%
Highside and fell right	2	33	53	88
	4.3%	5.8%	5.5%	5.6%
Left low-side - fell over to the left	5	**105**	203	313
	10.9%	18.3%	21.2%	19.8%
Right low-side - fell over to the right	9	**64**	171	244
	19.6%	11.2%	17.8%	15.5%
Topside, over the handlebars	11	**107**	**170**	**288**
	23.9%	18.7%	17.7%	18.3%
Other	0	40	66	106
	0.0%	7.0%	6.9%	6.7%
Uncertain/No Answer	15	175	237	427
	32.6%	2.6%	24.7%	27%
Total	**46**	**573**	**959**	**1578**
	100%	**100%**	**100%**	**100%**

The trajectory or the direction the body travels after a collision appears to be closely linked the type of crash. As an example, a rear end collision where the motorcycle rear-ends another vehicle would typically cause the rider to go over the front of the handlebars. The information from table 12a above and the following tables, 12b and 12c, is the comparison between motorcycles with and without ABS and whether the rider used the brakes prior to crashing.

Table 12b

Prior to crashing, did you apply the brakes?		Did your motorcycle have ABS brakes			
		No Answer /Uncertain	No	Yes	Total
Uncertain		*6*	*57*	*45*	*108*
No	Fell backwards	0	7	8	15
		0%	2%	3%	3%
	Highside and fell left	0	14	11	25
		0%	5%	4%	5%
	Highside and fell right	0	24	17	41
		0%	9%	7%	7%
	Left low-side - fell over to the left	3	**75**	**55**	133
		55%	**27%**	**21%**	24%
	Right low-side - fell over to the right	4	**47**	**34**	85
		89%	**17%**	**13%**	15%
	Topside, over the front of the handlebars	3	**38**	**43**	84
		33%	**13%**	**17%**	15%
	Other	0	21	18	39
		0%	7%	7%	7%
	Uncertain/No Answer	2	56	73	131
		22%	20%	28%	24%
	Total	**12**	**282**	**259**	**553**
		100%	**100%**	**100%**	**100%**

The comparison of riders whose motorcycles were equipped with ABS brakes and did not apply their brakes (table 12b) with those that did (table 12c), is instructive. There were n.259 whose motorcycle had ABS brakes but did not use them and there were n.258 who had ABS brakes and used them prior to crashing. Of those that fell Left low-side, 21% did not use their brakes compared to 17% who did use them. Of those that fell Right low-side, 13% did not use their brakes, while 10% did use them.

Finally, 17% who did not use their ABS brakes, fell topside (over the front of the handlebars) while 18% used their brakes. The proportion of those who were uncertain whether they had crashed or did not answer represents 30% of the respondents. As this is empirical data – we are unable to hypothesize what may have happened.

Table 12c

Prior to crashing, did you apply the brakes?		Did your motorcycle have ABS brakes			
		No Answer /Uncertain	**No**	**Yes**	Total
Yes	Fell backwards	0	8	11	19
		0%	1%	4%	2%
	Highside and fell left	3	26	10	39
		11%	4%	4%	4%
	Highside and fell right	2	23	13	38
		7.4%	4%	5%	4%
	Left low-side - fell over to the left	2	115	44	161
		7.4%	19%	17%	18%
	Right low-side - fell over to the right	5	113	27	145
		18.5%	19%	10%	16%
	Topside, over the front of the handlebars	5	118	47	170
		18.5%	20%	18%	19%
	Other	0	39	16	55
		0%	6%	6%	6%
	Uncertain/No Answer	10	163	90	263
		37%	27%	35%	30%
	Total	**27**	**605**	**258**	**890**
		100%	**100%**	**100%**	**100%**

In the case where the riders used their brakes prior to crashing, the proportion of those that fell Left low-side and did not have ABS brakes (19%), was similar to those that did (17%). While there was a notable difference for those that fell Right low-side – 10% with ABS and 19% without. The outcome for those who fell topside is similar – 18% with ABS and 20% without. This suggests that the type of brakes on the motorcycle (i.e. whether they were ABS or not) had little effect on the trajectory of the rider.

3.12 Trajectory (post-crash motion) and injury locations (type of injuries*)

The following tables indicate the type of injuries (*type of injuries in this study, means the location on the body of the injury) identified, depending on the trajectory (post-crash motion) of the respondents.

What these particular responses do not indicate is the severity of the injuries or whether the injuries resulted in time spent in hospital. Table 13a focuses on lower limb and pelvic injuries as well as upper limbs and indicates that the two. It shows that two trajectories, Left-low-side and Topside dominate injuries to these regions. Left low-side averaged 20% (excluding pelvic internal) and Topside averaged about 25%.

However, note that being thrown forward over the handlebars accounted for nearly half the pelvic internal injuries this suggests a role of the fuel tanks in groin injuries as highlighted in previous research Oeullet, JV and Hurt HH 1981[9], Meredith L et al 2016)[10]. Pelvic-internal injuries were uncommon – only 5% of the injuries reported.

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[9] Ouellet, JV & Hurt, HH, Jr., Groin injuries in motorcycle accidents, *Proceedings of 25th Conference of the American Association for Automotive Medicine,* San Francisco, CA 1981.
[10] Meredith, Lauren & Baldock, Matthew & Fitzharris, Michael & Duflou, Johan & Nevo, Ross & Griffiths, Michael & Brown, Julie. (2016). Motorcycle fuel tanks and pelvic fractures: A motorcycle fuel tank syndrome. Traffic injury prevention. 17. 10.1080/15389588.2015.1136061.

Table 13a

Trajectory	Lower limbs, including knees, feet and/or ankles		Upper limbs - arms, elbows, wrists, hands		Pelvic internal		Pelvic external	
	Fr	**%**	**Fr**	**%**	**Fr**	**%**	**Fr**	**%**
Fell backwards	16	2.4	10	1.9	1	1.4	0	0.0
Highside and fell left	37	5.5	30	5.7	2	2.7	5	5.8
Highside and fell right	47	7.0	41	7.8	5	6.8	5	5.8
Left low-side - fell over to the left	129	**19.2**	108	**20.6**	5	6.8	17	**19.8**
Right low-side - fell over to the right	97	14.4	75	14.3	8	11.0	10	11.6
Topside, over the front of the handlebars	130	**19.3**	123	**23.4**	27	**37.0**	18	**20.9**
Other	56	8.3	32	6.1	9	12.3	10	11.6
Uncertain/No Answer	160	23.8	106	20.2	16	21.9	21	24.4
Total	**672**	**100.0**	**525**	**100.0**	**73**	**100.0**	**86**	**100.0**

Once again 13b highlights the two dominating post-crash motions with the highest proportion of injuries as Left low-side and Topside. However, across the range of types of injuries, Topside dominates with an average of 30% for abdomen and chest injuries and Left low-side has an average of 20% for chest injuries.

Table 13b

Trajectory	Abdomen internal		Abdomen external		Chest internal		Chest external	
	Fr	**%**	**Fr**	**%**	**Fr**	**%**	**Fr**	**%**
Fell backwards	3	5.3	1	2.0	4	2.7	3	3.4
Highside and fell left	3	5.3	0	0.0	10	6.7	3	3.4
Highside and fell right	2	3.5	4	8.0	13	8.7	11	12.4
Left low-side - fell over to the left	3	5.3	7	14.0	26	**17.3**	20	**22.5**
Right low-side - fell over to the right	8	14.0	7	14.0	23	15.3	11	12.4
Topside, over the front of the handlebars	23	**40.4**	17	**34.0**	40	**26.7**	19	**21.3**
Other	6	10.5	4	8.0	16	10.7	6	6.7
Uncertain/No Answer	9	15.8	10	20.0	19	12	16	17.9
Total	**57**	**100.0**	**50**	**100.0**	**150**	**100.0**	**89**	**100.0**

Table 13c tabulates back and shoulder injuries by rider trajectories. In this case, the post-crash motion, Topside overwhelmingly dominates with 29% compared to the remaining trajectory types.

The question relating to back injuries was not asked, this was a shortfall in the survey, however the respondents who replied to the question about trajectory, were then asked to comment on "other injuries" and n.87 replied with details of the type of back injuries with the varied severity, that they had received[11].

[11] See Annex III in the report "Dynamics of Motorcycle Crashes" for details of back injuries.

Table 13c

Trajectory	Back		Shoulders	
	Fr	**%**	**Fr**	**%**
Fell backwards	5	5.7	9	2.6
Highside and fell left	9	10.3	25	7.1
Highside and fell right	9	10.3	35	10.0
Left low-side - fell over to the left	5	5.7	53	15.1
Right low-side - fell over to the right	10	11.5	52	14.9
Topside, over the front of the handlebars	27	**31.0**	95	**27.1**
Other	11	12.6	22	6.3
Uncertain/No Answer	11	12.6	59	16.9
Total	**87**	**100.0**	**350**	**100.0**

Table 13d provides details of neck, face, head and brain injuries and the Topside trajectory (post-crash motion) dominates with an average of 38.5% for all these types of injuries.

Table 13d

Trajectory	**Neck**		**Face**		**Head**		**Brain**	
	Fr	**%**	**Fr**	**%**	**Fr**	**%**	**Fr**	**%**
Fell backwards	4	3.0	1	2.0	3	3.8	1	1.7
Highside and fell left	6	4.5	4	8.2	4	5.1	2	3.4
Highside and fell right	9	6.7	0	0.0	8	10.3	0	0.0
Left low-side - fell over to the left	19	14.2	8	**16.3**	4	5.1	4	6.8
Right low-side - fell over to the right	15	11.2	6	12.2	6	7.7	9	15.3
Topside, over the front of the handlebars	48	**35.8**	16	**32.7**	35	**44.9**	24	**40.7**
Other	9	6.7	6	12.2	3	3.8	5	8.5
Uncertain/No Answer	24	17.9	8	16.3	15	19.3	14	23.8
Total	**134**	**100.0**	**49**	**100.0**	**78**	**100.0**	**59**	**100.0**

What the tables above highlight is that the trajectory is significant in establishing the percentages of injuries. Overwhelmingly, the Topside motion has the highest proportion of declared injuries for all types, with the exception of "external chest".

The Left low-side motion had the second highest proportion of type of injuries. As mentioned above, the type (or location) of injuries highlighted do not determine the severity of the injuries.

3.13 Topside – Over the front of the handlebars

A total of n.288 riders stated that their trajectory was Topside (compared to n.313 Left low-side) while, n.232 whose post-crash motion was "Topside" stated that they were injured (compared to n.206 Left low-side).

Overall, n.96 "Topside" were admitted to hospital (compared to n.25 Left low-side), whereas when the Trajectory was Topside, n.59 stayed in hospital between one to seven days while n.20 stayed in hospital between eight to 20 days and n.17 stayed in hospital for more than 20 days.

3.14 Crashed with and Trajectory of motorcycle post-crash

Table 14 below compares the post-crash motion to what the motorcycle crashed with and demonstrates that of the n.696 motorcycles that crashed with a car, 63.5% (n.183) of the motorcyclists' trajectory was Topside (n.288). Of the single vehicle crashes (n.191) where the rider lost control and did not crash against an object or vehicle, the predominant trajectories were Left low-side (18.8%) and Right low-side (19.3%).

Table 14

Crashed with	If you were separated from your motorcycle, which way did you go?								
	No Answer/ Uncertain	**Other**	**Fell back wards**	**High-side and fell left**	**High-side and fell right**	**Left lowside - fell over to the left**	**Right low side - fell over to the right**	**Topside, over the front of the handle bars**	**Total**
Bicycle	6	2	0	0	1	2	0	4	15
	1.4%	1.9%	0.0%	0.0%	1.1%	0.6%	0.0%	1.4%	1.0%
Bridge	0	0	0	0	0	0	0	1	1
	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.1%
Bus	2	0	0	0	1	0	0	1	4
	0.4%	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%	0.3%	0.3%
Car	198	45	18	27	35	102	88	183	696
	47.3%	42.5%	48.6%	36.0%	39.8%	32.6%	36.1%	63.5%	44.1%
Flying objects (e.g.birds or insects)	1	2	0	0	0	2	0	1	6
	0.2%	1.9%	0.0%	0.0%	0.0%	0.6%	0.0%	0.3%	0.4%
Large animal (e.g. moose, horse, deer)	10	4	4	1	2	3	6	5	35
	2.4%	3.8%	10.8%	1.3%	2.3%	1.0%	2.5%	1.7%	2.2%
Motorcycle/scooter moped	22	4	4	6	7	15	14	10	82
	5.2%	3.8%	10.8%	8.0%	8.0%	4.8%	5.7%	3.5%	5.2%
Other	26	9	3	9	10	30	12	9	108
	6.1%	8.5%	8.1%	12.0%	11.4%	9.6%	4.9%	3.1%	6.8%
Pedestrian	3	0	0	0	0	2	1	0	6
	0.7%	0.0%	0.0%	0.0%	0.0%	0.6%	0.4%	0.0%	0.4%
Road hump	4	0	1	0	3	3	5	3	19
	0.9%	0.0%	2.7%	0.0%	3.4%	1.0%	2.0%	1.0%	1.2%
Road side (crash) barrier	13	6	1	5	3	11	6	5	50
	3.1%	5.7%	2.7%	6.7%	3.4%	3.5%	2.5%	1.7%	3.2%
Road side (crash) barrier with motorcycle guard rail	3	0	0	0	0	3	0	1	7
	0.7%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.3%	0.4%
Single vehicle	35	15	1	4	8	59	47	22	191
	8.3%	14.2%	2.7%	5.3%	9.1%	18.8%	19.3%	7.6%	12.1%
Small animal dog, fox	2	1	0	1	0	1	1	2	8
	0.4%	0.9%	0.0%	1.3%	0.0%	0.3%	0.4%	0.7%	0.5%
Tractor (agricultural vehicle)	2	1	0	0	0	0	1	0	4
	0.4%	0.9%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.3%
Truck	4	4	0	1	1	1	2	3	16
	0.9%	3.8%	0.0%	1.3%	1.1%	0.3%	0.8%	1.0%	1.0%
Truck with trailer/s	4	0	0	0	2	1	0	2	9
	0.9%	0.0%	0.0%	0.0%	2.3%	0.3%	0.0%	0.7%	0.6%
Tuk tuk (rickshaw)	1	0	0	0	0	0	0	0	1
	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Van	18	5	2	3	2	12	8	21	71
	4.3%	4.7%	5.4%	4.0%	2.3%	3.8%	2.9%	7.3%	4.4%
Uncertain/No Answer	72	8	3	18	13	66	53	15	249
	17.0%	7.5%	8.1%	24%	14.8%	21%	21.7%	5.2%	15.7%
Total	**427**	**106**	**37**	**75**	**88**	**313**	**244**	**288**	**1578**
	100%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

3.15 Days in Hospital and brakes

Overall there were n.109 riders whose motorcycles had ABS who were recovered in hospital ranging from between one day to n.180 days. Of these n.41 applied their brakes prior to crashing while n.50 did not (n.15 were uncertain). Conversely there were n.185 riders whose motorcycles did not have ABS and who were hospitalized ranging from one day to n.183 days. Of these n.115 applied their brakes prior to crashing and n.47 did not (n.21 were uncertain).

4 Findings

The findings from the report “Dynamics of Motorcycle Crashes” relating to post licence training is important in order to understand whether the courses that the riders participate in have any effect on their ability to avoid crashing. Of the respondents, 43% indicated that they had done some form of post licence training, but still crashed. A shortfall of the survey was that the question of when the respondents did training, was not asked and this may have an influence on their skills and knowledge in emergency situations.

As an aside, but worth considering from the Dynamics report, is the common hypothesis suggesting that younger riders though less experienced, take greater risks in terms of speed. However, the responses indicate that the correlation between age and speed appears to be random.

Most relevant for this paper is those riders who took part in specific training for braking with ABS represented 19.9% (n.314). Of these, 65% (n.204) indicated that they were riding motorcycles with ABS brakes at the time of the crash.

Yet an interesting finding here is that riders on ABS-equipped motorcycles were significantly less likely to brake than riders without ABS: only half the riders on ABS-equipped motorcycles reported braking before they crashed compared to two-thirds of those on a motorcycle without ABS.

Technology on motorcycles has the purpose of aiding the rider to control the motorcycle in order to be able to accelerate, ride, lean and stop. As the findings of this paper demonstrate, over a third of the respondents (35%) did not use their brakes prior to crashing and of these, n.259 (46.8%) had ABS brakes fitted. Also to keep in mind is that both the Hurt and Thailand studies found that a substantial minority of riders seem to take no evasive action before they crashed – 30% in the Hurt study and nearly half in Thailand. So it should be no surprise that many riders in this survey would report taking no evasive action. And indeed, about 38% said they did no braking.

On the other hand, this suggests that brake performance had a role in 65% of the crashes, which is more than the 54% Kramlich & Sporner[12] calculated 20 years ago, when ABS was rather new on the market.

The distribution of post-crash motion of riders with and without ABS and those who had applied brakes vs. those who had not, clearly indicate that ABS changes crash records. Considering the technical function of an ABS, it may be argued that ABS primarily reduces low-side crashes, which leads to a higher share of top-side motion. But the methodological nature of this study does not allow to conclude on a crash-reduction potential of ABS.

Motorcycles more than any other form of transport have developed and modernised such that technology is an integral part of how the machine operates but more importantly, how this technology interacts with the rider and his/her ability to control the technology.

This study provides evidence that indicates that the link between speed and the seriousness of injuries is random, this is based on the correlation of speed, the type (or location) of injuries and the number of days that the rider spent in hospital and in rehabilitation.

[12] Kramlich, T., & Sporner, A. (2000). Zusammenspiel aktiver und passiver Sicherheit bei Motorradkollisionen. GDV, Institut für Fahrzeugsicherheit, München.

What is possibly the most important finding of this study was that the mechanism of each crash, in particular, the trajectory of the rider post-crash, determines not only the type and range of injuries but also the severity of the injuries in terms of the area of the injuries on the body.

The identification of post-crash motion is used in motorcycle racing circuits to explain the trajectory of the motorcyclists when they separate from the motorcycle after impact with an object, roadside furniture or infrastructure or because the rider has lost control of the motorcycle. These definitions are to understand how the rider falls and what the potential type of injuries may occur from the mechanism of the fall. These definitions are not universally used and it would be helpful to decide amongst analysts that a guide should be adopted to facilitate comparative research.

The post-crash motion “Topside” occurred in 63% of those cases where the rider collided with a car. In terms of injuries this type of trajectory dominates both the range of type or location of injuries and the severity.

The following types of trajectories: Left Low-side and Right Low-side also have high levels of injuries by type. But compared to the Topside trajectory, less time was spent in hospital.

This study suggests that the rider's trajectory in the crash strongly influences the range of injuries riders sustain and also the injury severity. In nearly every body region, "Topside" – ejection forward over the handlebars – accounted for more injuries than any other trajectory. In addition, riders who ejected Topside were more likely to be hospitalized than riders who had some other trajectory and they were more likely to be hospitalized for longer.

Annex one provides a sample of the information available in the study based on the comments of motorcyclists who describe the circumstances of the crash. The sample of six riders is an example of the depth and wealth of information through the responses of 1578 motorcyclists throughout 30 countries.

The full report “Dynamics of Motorcycle Crashes” can be found here:

https://investigativeresearch.org/the-dynamics-of-motorcycle-crashes-2020/

Annex One: Case study of six motorcyclists who crashed

Profile of the Six Motorcyclists

- Three from France, one from Norway, One from Germany and one from the UK. All male but two accompanied by female riders.
- Ages varied from 16 to 62 (average age 35). Five had full licence and one had A1 licence (125cc).

- Four had full face helmets and two had modular (flip ups). All six wore armoured jackets and five wore armoured trousers. All wore gloves and boots.
- Average annual distance ridden was 13166 (minimum 6000 kilometres, maximum 25000 kilometres). Average number of years riding was 12 (minimum 1 year, maximum 40 years).
- Four of the riders had taken part in emergency braking courses.

- Four of the motorcycles were Naked Street bikes and two were adventure bikes.
- Engine cc for two was 800cc and 600cc respectively, one 125cc and one 1050cc
- Three of rider riders were travelling at speeds of between 81 to 90 kph, one was travelling at estimated speeds of between 71 to 80 kph and one was travelling at estimated speeds of between 31 to 40 kph and another at estimated speeds of between 31 to 40 miles per hour.
- All motorcycles were equipped with ABS.

- Four of the riders were travelling in the morning (between 8 am and 12 noon) and two in the early afternoon.
- Weather conditions were good – in five cases it was sunny and in one case it was overcast (cloudy).
- In five cases the road conditions were good and in one case there was gravel.

Table 15

Estimated Speed	Type of road	Crashed with	Impact on MC/ Post-crash motion	Injuries, days in hospital/rehab.	Comments
31-40 mph	Rural road right hand bend	Single vehicle	Didn't separate	Lower limbs 14 (hosp.) 365 (rehab.)	Road had been resurfaced and gravel had built up on the bend. There was a depression on the outside of the bend and gravel had pooled in it. I went into a field and clipped a dike guard. Left leg was smashed back against the bike. Fibula tibia 3 metatarsals were all broken.
31-40 kph	Urban road (straight + Cross road)	Car	Frontal/Topside	Upper limbs/Shoulders 38 (hosp.)	The driver of the car lost his licence for driving recklessly and because he didn't yield.
81-90 kph	Urban road (straight + T junction)	Truck	Frontal/ highside-right	Lower and upper limbs 180 (hosp.)	The truck cut me off at the last moment, so I hit it head on.
81-90 kph	Rural road (Straight + T junction)	Car	Lateral, right side/Topside	9 (hosp.), 90 (rehab.)	A collision of two motorcycles against a car. Two riders seriously injured - my wife and myself, but she died one week later. My wife hit the front, I hit the side (the car was turning square on into our way). Evidently, the person in the car, elderly, 86 years old if I remember correctly, cut us off because he thought he was seeing 'bicycles'.
81-90 kph	Rural Straight road	Car	Frontal/topside	Lower + Upper limbs 22 (hosp.) 600 (rehab.)	I was passing a car which turned left without using the indicators. I was thrown more than 30 meters away while my motorcycle went under the car. I owe my survival in part to the reflex that I had of letting go of the handlebars and standing on my toe clips. I specify that I was an "all weather" biker and experienced. But, one cannot drive in place of the others ...

Table 15 continued

Estimate Speed	**Type of road**	**Crashed with**	**Impact to MC/ Post-crash motion**	**Injuries, days in hospital/rehab.**	**Comments**
71-80 kph	Rural Straight road	Car and motorcycle	Frontal/Topside	Upper limbs, pelvis. 30 (hosp.), 30 (rehab.)	The crash happened just after a left-hand bend on a straight part of the road. Just after the bend, a car was standing still on this 100 kph limit road. No Alarm lights, no indication of car trouble. Not parked with two wheels on the side. Just in the middle of my lane. My wife was on her R1200GS riding in front of me. Just after the left-hand bend, the car - a dark black Porsche was there in the middle of our lane. It took a fraction of a second for my wife to realize that the car was not moving. She had to decide to go around the car or emergency brake. She chose the latter because the "only reason" a car would be standing still on this 100KM road, was that the car was going to make a U-Turn. My wife made an emergency stop. Because of our position on the road (just after the bend) my wife was blocking my view. I could not see the car. I saw her braking lights, but not for what she was braking. It took a split second before I realized that she was not just braking, but emergency braking. I also emergency braked. My position was now "staggered" (not in a straight line behind my wife, but to the left of her). Now I could see the car as well. My wife realized that she could not stand still before she was going to hit the car so at the last moment she moved to the left to pass the car. By doing this, she was coming into "my line". Since I started braking just a bit later than my wife, I was still driving faster and hit my wife in the back of the motorcycle. She went low-side, going across the tarmac ending up in a ditch. She only had a scratch on her elbow because her Rukka protection did not stay in place. I went high-side and ended up on the tarmac. My injuries were: broken collar bone, three broken ribs, broken pelvis front and back on both sides and a pneumothorax. This all happened in two or three seconds. We didn't hit the car.

Annex two: Acknowledgements

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Cover photo:Joachim Sjöström

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Research Team

The research team has wide experience in the study of motorcycle crashes such as those conducted by James Ouellet who co-authored the seminal Hurt Report as well as other ground-breaking studies on motorcycle crash investigations[13]; Elaine Hardy’s involvement in EU PTW research projects and studies of motorcycle safety, including reporting crash investigations[14].

Research on infrastructure and training by Martin Winkelbauer[15] and in-depth accident investigation (e.g.MAIDS, SaferWheels, DaCoTA) by Dimitri Margaritis[16].

The latter two researchers collaborated in the OECD/ITF research report, “Improving Safety for Motorcycle, Scooter and Moped Riders[17].

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