Motorcycle crashes resulting in hospital admissions in South Australia: Crash characteristics and injury patterns

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Key Findings

- 763 motorcyclists' hospital records linked to crash data and forensic blood tests;
- Crash characteristics and injuries examined and compared to 1617 car drivers;
- Motorcyclists were younger, more likely men and learners, less likely over .05 BAC;
- More likely crash in 50 and 80km/h area, daylight, weekends, dry roads and weather;
- Higher severity, longer in hospital, more likely injured in multiple body regions.

Abstract

Motorcycle riders have a high risk of serious injury if they crash. To assist with identification of countermeasures, the present study examined records from the Royal Adelaide Hospital (RAH) in South Australia for 763 motorcyclists (including scooter riders) admitted between January 2008 and November 2010 and between April 2014 and December 2016. Records were linked with police-reported crash data and results of forensic blood tests for alcohol and drugs. When compared with 1617 car drivers admitted to the RAH over the same periods, motorcyclists were younger, were more commonly male, more likely to hold a learner permit, less likely to hold a provisional licence, less likely to be over the legal alcohol limit and less likely to be at-fault in multiple vehicle crashes. Their crashes were more likely to be single vehicle crashes (specifically roll over, left road – out of control and hit object/animal/pedestrian on road crashes) and were more common on weekends, during the afternoon, on sloping roads, on curved roads, on roads with speed limits of 50 and 80 km/h, during daylight hours, in dry weather and on dry roads. They had a higher severity of injury than car drivers, spent longer in hospital, and were more likely to sustain injuries to multiple body regions. Linear regression showed that older age, higher blood alcohol concentration and higher speed limit increased injury severity for motorcyclists. Based on present findings, motorcycling safety can be improved through countermeasures related to Graduated Licensing Systems, infrastructure, motorcycle technology and protective clothing.

Keywords

Motorcycle, Scooter, Crash Characteristics, Injury Severity, Hospital Data, Countermeasures

Introduction

Riding a motorcycle or scooter is a high-risk mode of transportation, with considerably higher rates of serious or fatal injuries than other road users (Johnston, Brooks, & Savage, 2008; Keall & Newstead, 2012; Van Eslande & Elvik, 2012; Lin & Kraus, 2009). Keall and Newstead (2012) found that the risk of injury is greater for motorcyclists than for occupants of small cars in New Zealand, while Van Eslande and Elvik (2012) reported that in Norway motorcycles and cars have similar crash rates but that serious injuries occur with greater frequency for motorcyclists. In South Australia, motorcyclists account for a substantial proportion of the State's road trauma, comprising 17% of serious injuries and 12% of fatalities between 2012 and 2016 (Baldock, 2018).

The high injury rates for motorcyclists have prompted a number of studies examining injury patterns among crashed motorcyclists. In a review of literature regarding motorcycle crashes and injuries, Lin and Kraus (2009) found that riders often sustain multiple injuries in a crash, with the most common site being the lower extremities. The most frequent injury in fatal crashes was to the head (contributing to about 50% of motorcycle deaths) followed by injury to the chest and abdominal areas (contributing to between 7% and 25%). Forman et al. (2012) examined hospital discharge data for 12,994 riders in eight European countries. Injuries to a lower extremity (26%) and upper extremity (20%) were most common, followed by traumatic brain injuries (18.5%).

Other studies have found that spinal injuries tend to occur more frequently with single vehicle crashes, particularly those involving collisions with fixed objects (Zilkipli et al., 2012); that thoracic injuries are common following collisions with barriers (Bambach, Grzebieta, & McIntosh, 2012; Daniello & Gabler, 2012); and that fatal crashes are associated with older riders, collisions with trees, night riding, curved roads and local roads (Huang & Lai, 2011). A higher risk of injury has been linked to failure to wear protective clothing (de Rome et al., 2011; de Rome, Ivers, et al., 2012), and right angle or turn across path crashes, speeding and alcohol use (Rifaat, Tay, & De Barros, 2012).

The present study obtained data from the Royal Adelaide Hospital (RAH) in South Australia for two time periods (January 2008 to November 2010; April 2014 to December 2016). These data were linked with police-reported crash data and the results of blood tests for alcohol and drugs. The aim was to undertake an examination of crashes in which a rider of a motorcycle or scooter was injured, in terms of rider characteristics, crash characteristics, injury patterns and injury severity, and make comparisons to crashes in which a car driver was injured. It was decided that the comparison sample would be comprised of crashes involving car drivers as, firstly, with regard to injury patterns and severity, cars offer vehicular protection while motorcycles do not, and this comparison would potentially identify injury patterns unique to motorcyclists. Secondly, with regard to rider and crash characteristics, cars are the most common vehicles both on the road and involved in crashes, and comparisons to car crashes would identify what is unique about both the people who ride motorcycles and the crashes they are involved in.

Methods

Data

Data were collected for road users who were injured in a crash and were admitted (four hours or more) to the RAH over two time periods, January 2008 to November 2010 and April 2014 to December 2016. These data included 375 crash-involved motorcyclists for the 2008 to 2010 period (34 scooter and 341 motorcycle) and 388 for the 2014 to 2016 period (36 scooter and 352 motorcycle). There were also 803 crash-involved car drivers (and car derivatives such as utility vehicles, station wagons and sports utility vehicles) for the 2008 to 2010 period and 814 for the 2014 to 2016 period for comparison. Data included medical assessments and interventions undertaken during hospitalisation, police-reported crash information, and forensic tests for alcohol and drugs. One of the authors (Tori Lindsay) attended the RAH to collect the hospital data and linked these data to police-reported data and alcohol and drug tests through details of the crash (e.g. date) and the participants (e.g. date of birth, driver licence number) and vehicles (e.g. make, model, registration number).

Medical data

The medical data included ambulance records, emergency department records, and hospital in-patient records. Ambulance records included information about the crash gathered at the scene and the initial care given to the injured participants. Emergency department records included injury surveys. Hospital in-patient records included patient demographics, injury and medical intervention information, and discharge details.

Injuries were coded according to the Abbreviated Injury Scale (AIS), which was developed by the Association for the Advancement of Automotive Medicine to classify the threat to life associated with injuries. Each separate injury is given a score on a scale from one (minor) to six (currently untreatable) and is categorised by the body region in which it occurred (six regions: abdomen, chest, external, extremities, face and head/neck). A maximum AIS (MAIS) was also coded for the injury with the highest AIS score within each separate body region, as a person may receive a number of separate injuries to a specific region.

Each injured crash participant's AIS scores were converted to an Injury Severity Score (ISS) to give an overall measure of injury severity. ISS is calculated by taking the three most severely injured body regions, squaring the number given to the most severe injury and summing these numbers. Only numbers one to five are used, giving a maximum ISS of 75. If any injury has an AIS score of six (untreatable), ISS is automatically set to the maximum 75.

Police-reported crash data

Police-reported crash data were obtained from the Traffic Accident Reporting System (TARS). TARS data included: date, time, day of week and location (metropolitan or rural) of the crash; vehicle type (e.g. motorcycle, car); licence types of crash participants (full, learner, provisional, probationary, unlicensed or disqualified); description of the crash; crash type (single or multiple vehicle); vertical alignment (slope or level), horizontal alignment (curved or straight), road surface (unsealed or sealed) and speed limit at the crash location; light conditions (day or night), weather conditions (raining or dry) and road conditions (wet or dry) at the time of the crash; and the injury status of those involved. At-fault status (yes or no) for the drivers or riders involved is also recorded in TARS.

Blood tests for alcohol and drugs

Since 1972, drivers, motorcycle riders, vehicle occupants and pedestrians over the age of 14 years, who present to hospital as a result of a crash, have been required to undergo testing for blood alcohol concentration (BAC) in South Australia. Since July 2008, road users have also been screened for three proscribed drugs: Methamphetamine, Delta-9-Tetrahydrocannabinol (THC) and 3,4-Methylenedioxymethamphetamine (MDMA). Blood samples (taken within eight hours following the crash) are tested by the South Australian Forensic Science Centre. These results were made available for the present study.

Analyses

Sample characteristics (age, gender, licence type, helmet use, blood test results, and at-fault status), crash characteristics (day of week, time of day, crash location, crash type, vertical and horizontal alignment of the road, road surface, speed limit, and light, weather and road conditions), and injury patterns and severity (length of hospitalisation, ISS, AIS) were examined for motorcycle riders, and comparisons made to car drivers. Frequency counts, means, chi-square tests and independent-samples t-tests were used. Additionally, linear regression was used to examine whether several independent variables (age, gender, crash location, BAC level, drug test result, road surface, type of crash and speed limit) predict injury severity (ISS – dependent variable) for motorcyclists. For all analyses, an alpha level of 0.05 was used for statistical significance.

Results

Sample Characteristics

The age and gender distribution of the total sample of crash-involved motorcycle riders (both time periods combined) is shown in Table 1. Those aged from 20 to 59 comprised 84.4% of the crash-involved population; females comprised just 6.9%. Car drivers are also shown, with a greater representation of females (41.9%) and people aged over 60 (25.9% compared to 8.4% of motorcyclists). The mean age of 39.3 years (*SD*=14.7) for motorcyclists was significantly lower than the mean of 44.9 years (*SD*=20.9) for car drivers ($t(2378)=6.7$, $p<.001$).

Five hundred and eighty-one riders held a full licence (78.8% of known), 43 held a learner permit (5.8%), 70 held a provisional licence (9.5%), seven held a probationary licence[1] (0.9%), 28 were unlicensed (3.8%), and eight had been disqualified from driving (1.1%). Licence status was unknown for 87 motorcyclists. In comparison, 1,253 car drivers held a full licence (80.1% of known), 27 held a learner permit (1.7%), 203 held a provisional licence (13.0%), 11 held a probationary licence (0.7%), 58 were unlicensed (3.7%), and 13 were disqualified (0.8%). Licence status was unknown for 52 drivers. A statistically significant difference ($\chi^2_{(5)}=33.8$, $p<.001$) was found between these distributions, with a larger proportion of crash-involved motorcyclists holding a learner permit and smaller proportion holding a provisional licence.

Of the 608 riders for whom BAC was known, 51 (8.4%) were above the legal limit of 0.05g/100ml. Of the 1360 drivers for whom BAC was known, 274 (20.1%) were above the legal limit. These numbers included two riders and eight drivers with a positive BAC below 0.05 who held provisional licences only and were required to have a BAC of zero. This difference was statistically significant ($\chi^2_{(1)}=42.1$, $p<.001$). Of the 410 riders for whom drug status was known, 77 (18.8%) were positive. Thirteen of the 77 also had a BAC over 0.05. Of the 928 car drivers for whom drug status was known, 149 (16.1%) screened positive. Thirty-three of the 149 also had a BAC above 0.05. The small apparent difference between motorcyclists and drivers in the likelihood of testing positive to a proscribed drug was not statistically significant ($\chi^2_{(1)}=1.5$, $p=.220$).

Five hundred and eleven (77.7% of known) motorcyclists were found to be at-fault for their crash, while 147 (22.3%) were not at-fault, and at-fault status was unknown for 105. In comparison, 1232 (76.5% of known) drivers were at-fault, while 378 (23.5%) were not at-fault, and at-fault status was unknown for 7. The small difference in the distributions was not statistically significant ($\chi^2_{(1)}=0.3$, p=.560). However, when at-fault status was examined in multiple vehicle crashes only (single vehicle crashes removed), 40.6% of motorcyclists were at-fault compared 56.1% of car drivers. This difference was statistically significant ($\chi^2_{(1)}=23.6$, p<.001), indicating that motorcyclists are less likely to be at-fault in crashes involving several vehicles.

There were 708 motorcyclists wearing a helmet (98.3% of known) at the time of the crash, while helmet status was unknown for 43. Twelve riders were not wearing a helmet

Table 1. Age and gender of crash-involved motorcyclists compared to crash-involved drivers of cars

	Motorcyclists			Drivers of cars		
Age category	**Male % (*n*=710)**	**Female % (*n*=53)**	**Total % (*n*=763)**	**Male % (*n*=939)**	**Female % (*n*=678)**	**Total % (*n*=1617)**
16-19	7.2	7.5	7.2	9.5	8.1	9.0
20-29	24.9	24.5	24.9	20.8	23.9	22.1
30-39	19.9	18.9	19.8	17.7	13.9	16.1
40-49	20.0	22.6	20.2	16.5	13.3	15.2
50-59	19.2	24.5	19.5	10.9	13.3	11.9
60-69	6.2	1.9	5.9	8.1	10.5	9.1
70-79	2.3	0.0	2.1	7.7	9.9	8.6
80+	0.4	0.0	0.4	8.9	7.2	8.2
Total	100.0	100.0	100.0	100.0	100.0	100.0

and an inspection of these cases revealed that eight were above 0.05 BAC and four tested positive to THC.

Comparing Characteristics of Crashes Involving Motorcyclists and Car Drivers

Table 2 compares crashes involving motorcyclists to those involving car drivers on a number of variables. The crashes of motorcyclists were overrepresented on weekends, during the afternoon, in single vehicle crashes, on sloping roads, on curved roads, on roads with speed limits of 50 and 80 km/h, during daylight hours, in dry weather and on dry roads.

Greater information for crash type was available for the 2014 to 2016 data (crashes only classified as single or multiple vehicle for 2008 to 2010 data). There were 22 crashes involving motorcyclists for the 2014 to 2016 data that were side swipe crashes (5.8% of known), 101 roll over (26.7%), 38 right turn (10.1%), 54 right angle (14.3%), 38 rear end (10.1%), 14 left road – out of control (3.7%), 16 hit object/animal/pedestrian on road (4.2%), 16 head on (4.2%), and 79 hit fixed object/parked vehicle (20.9%). In comparison, there were 36 crashes involving car drivers for the 2014 to 2016 data that were side swipe crashes (4.4% of known), 48 roll over (5.9%), 79 right turn (9.7%), 154 right angle (19.0%), 92 rear end (11.3%), 7 left road – out of control (0.9%), 6 hit object/animal on road (0.7%), 81 head on (10.0%), and 308 hit fixed object/parked vehicle (38.0%). A statistically significant difference ($\chi^2_{(8)}$=156.1, p<.001) was found between these distributions. Roll over, left road – out of control and hit object/animal/pedestrian on road crashes were more common for motorcyclists, while right angle, head on and hit fixed object/parked vehicle crashes were more common for car drivers.

Examining injury patterns and severity of crashed motorcyclists

Table 3 shows the distribution of length of hospitalisation (in days) for motorcyclists and drivers. This table only includes those who were hospitalised, so it takes no account of the proportion of persons involved in injury crashes who were not injured severely enough themselves to attend hospital. Also, cases in which the motorcyclist or driver died after a period of hospitalisation were excluded. The most common length of hospitalisation for motorcyclists was between one and five days (40.1%). Drivers were more likely to require less than one day of hospitalisation (34.8% versus 17.3%), while motorcyclists were more likely to require between six and ten days (16.9% versus 11.9%) and between 11 and 15 (10.7% versus 6.1%) days. The difference between these two distributions was statistically significant ($\chi^2_{(8)}$=91.4, p<.001).

The hospital data did not include AIS scoring of injuries for car drivers for the 2008 to 2010 period. Consequently, only data from the 2014 to 2016 period were used for the purposes of comparing ISS between motorcyclists and drivers. The mean ISS of 9.2 (*SD*=7.8) for motorcyclists was statistically significantly higher than the mean of 6.4 (*SD*=7.8) for drivers (t(1192)=5.7, p<.001).

ISS could be examined according to additional categories of crash type for the 2014 to 2016 data for motorcyclists (as mentioned earlier crashes were only classified as single or multiple vehicle for the 2008 to 2010 data). The mean ISS for each type was: side swipe = 9.8 (*SD*=6.7), roll over = 7.7 (*SD*=6.7), right turn = 8.8 (*SD*=7.8), right angle = 7.3 (*SD*=6.1), rear end = 9.6 (*SD*=7.4), left road – out of control

Table 2. Characteristics of crashes involving injured motorcyclists compared to injured car drivers

Variable	Test statistic	Nature of difference
Day of week	$\chi^2_{(6)}$=25.1, p<.001*	Motorcycle crashes more common on weekends (39 vs 29%)
Time of day	$\chi^2_{(3)}$=49.5, p<.001*	Motorcycle crashes more common during the afternoon (50 vs 39%), car crashes between midnight and 6am (5 vs 13%)
Crash location	$\chi^2_{(1)}$=2.7, p=.103	No difference, metro or rural (50-50% vs 54-46%)
Single/multiple vehicle	$\chi^2_{(1)}$=5.0, p=.025*	Motorcycle crashes more commonly single vehicle (53 vs 48%)
Vertical alignment	$\chi^2_{(3)}$=80.3, p<.001*	Motorcycle crashes more common on sloping roads (23 vs 9%)
Horizontal alignment	$\chi^2_{(1)}$=25.7, p<.001*	Motorcycle crashes more common on curved roads (32 vs 22%)
Road surface	$\chi^2_{(1)}$<0.1, p=.872	No difference, sealed or unsealed (96% sealed for both groups)
Speed limit	$\chi^2_{(7)}$=58.3, p<.001*	Motorcycle crashes more common on roads with speed limits of 50 (21 vs 17%) and 80 km/h (20 vs 11%), car crashes on roads with speed limits of 100 km/h or higher (28 vs 19%)
Light conditions	$\chi^2_{(1)}$=52.5, p<.001*	Motorcycle crashes more common during daylight (80 vs 65%)
Weather conditions	$\chi^2_{(1)}$=13.1, p<.001*	Motorcycle crashes more common in dry weather (95 vs 90%)
Road conditions	$\chi^2_{(1)}$=16.9, p<.001*	Motorcycle crashes more common on dry roads (93 vs 87%)

* p<.05.

Table 3. Length of hospitalisation in days for motorcyclists and drivers of cars or SUVs, January 2008 to November 2010 and April 2014 to December 2016

Number of days	Number of riders	% of included	Number of drivers	% of included
< 1	130	17.3	548	34.8
1-5	301	40.1	554	35.2
6-10	127	16.9	187	11.9
11-15	80	10.7	96	6.1
16-20	33	4.4	58	3.7
21-25	29	3.9	42	2.7
26-30	16	2.1	20	1.3
31-35	4	0.5	23	1.5
36 +	31	4.1	47	3.0
Total included cases	751	100.0	1575	100.0
Excluded cases[a]	12		42	
Total of all cases	763		1617	

[a] Cases in which the motorcyclist or driver died after a period of hospitalisation were excluded

= 11.8 (*SD*=8.2), hit obstacle/animal/pedestrian on road = 10.4 (*SD*=8.4), head on = 11.7 (*SD*=6.9), and hit fixed object/parked vehicle = 10.8 (*SD*=9.1). There were different numbers of cases for each of the crash types and some had small numbers (e.g. 14 for left road – out of control) which made examinations of statistical significance difficult. Therefore, these results should be viewed as indicative only that injury severity may be highest for left road – out of control and head on crashes.

Table 4 shows MAIS for each of the six AIS body regions for motorcyclists and drivers. Again, only data from the 2014 to 2016 period were used. The body regions featuring most prominently for motorcyclists were the extremities (243 cases), external regions (241 cases), the chest (116 cases) and the head/neck (100 cases). Facial injuries were the least common. The areas with the most injuries with a MAIS value of 4 or more were the chest (17 cases) and the abdomen (9 cases). In comparison, external regions (429 cases) featured most commonly for car drivers, followed by the head/neck (253 cases), the chest (244 cases) and the extremities (205 cases.) As with motorcyclists, facial injuries were the least common. The areas with the most injuries with a MAIS value of 4 or more were the chest (18 cases) and the head/neck (17 cases). Ninety-six motorcyclists (25.5% of cases with AIS recorded) had injury to one body

Table 4. MAIS for each body region for injured motorcyclists and car drivers, April 2014 to December 2016

MAIS	Abdomen	Chest	External	Extremities	Face	Head/Neck
Motorcyclists						
1	4	2	234	17	16	3
2	38	37	7	175	16	71
3	7	60	0	48	1	23
4	6	12	0	3	0	2
5	3	5	0	0	0	1
Total	58	116	241	243	33	100
Car drivers						
1	5	23	417	12	40	58
2	71	98	11	148	23	132
3	16	105	0	42	1	46
4	4	12	1	3	0	7
5	1	6	0	0	0	10
Total	97	244	429	205	64	253

Table 5. Results of linear regression to predict injury severity (ISS) for motorcyclists, January 2008 to November 2010 and April 2014 to December 2016

Independent variables	B[a]	Beta[b]	*t*	*p*-Value
Age	.09	.15	3.03	*.003
Gender	2.34	.07	1.43	.155
BAC level	1.29	.22	4.32	*<.001
Drug test result	.14	.01	.14	.889
Road surface	.14	<.01	.05	.957
Type of crash	.82	.05	.96	.336
Speed limit	.64	.15	2.82	*.005

[a] The results for B are unstandardised coefficients.
[b] The results for Beta are standardised coefficients.
* p<.05.

region and 281 (74.5% of cases with AIS recorded) had injuries to two or more regions. In comparison, 272 (39.9% of cases with AIS recorded) car drivers had injury to one body region and 410 (60.1% of cases with AIS recorded) had injuries to multiple regions. The difference was statistically significant ($\chi^2_{(1)}$=22.3, p<.001), indicating that motorcyclists more commonly have injuries to multiple body regions.

Finally, linear regression was used to examine the effects of several variables on injury severity for motorcyclists from both periods. The dependent variable was ISS and the independent variables were: age, gender (male or female), BAC level (zero, less than 0.050, 0.050-0.079, 0.080-0.099, 0.100-0.149, 0.150-0.199 and 0.200-0.249), drug test result (positive or negative), road surface (sealed or unsealed), type of crash (single or multiple vehicle) and speed limit (40, 50, 60, 70, 80, 90, 100 and 110 km/h). The 'Enter' method was used to enter all independent variables in the model simultaneously. The model was statistically significant, (F(7, 372)=6.1, p<.001), with the independent variables accounting for 8.7% of the variance in ISS (adjusted R^2). Table 5 shows that injury severity was higher for older motorcyclists, motorcyclists with higher BAC, and crashes in areas with higher speed limits.

Discussion

This study examined motorcycle (and scooter) crashes in which the rider was injured and admitted to hospital, in terms of rider characteristics, crash characteristics, injury patterns and injury severity. The findings are summarised and discussed in the following sections.

Sample Characteristics

Crash-involved motorcyclists were younger, more commonly male, more likely to hold a learner permit, less likely to hold a provisional licence, less likely to be over the legal BAC limit and less likely to be at-fault in multiple vehicle crashes than a comparison sample of crash-involved drivers. Only 12 motorcyclists were not wearing a helmet (1.5% of known), which is reflective of compulsory helmet laws in Australia. Patterns and severity of injury to unhelmeted riders could not be examined due to the small number; however, the relationship between non-use of helmets and increased risk of head injury (Rutledge & Stutts, 1993) and increased overall injury severity has been demonstrated in other studies (Brown, Hejl, Bui, Tips, & Coopwood, 2011; Nakahara, Chadbunchachai, Ichikawa, Tipsuntornsak, & Wakai, 2005; Rowland et al., 1996).

Crash-involved motorcyclists were younger and more commonly held a learner permit, consistent with learner riders being permitted to ride on the road unsupervised in South Australia. Crash risk during this period of learning would be high. Indeed, it has been shown that novice motorcyclists have a higher risk of crashes per unit of exposure than more experienced riders (Andrea, 2006). In comparison, learner car drivers are required to be supervised. It is noteworthy then that crash-involved car drivers in the present study more commonly held a provisional licence, which is when they are first allowed to drive unsupervised. Research by Austroads (2008) has shown that car drivers with a provisional licence have a much higher crash risk than car drivers with a learner permit.

The finding that crash-involved motorcyclists were more commonly male is likely to be due, at least in part, to motorcycle riding being more popular amongst males (Auster, 2001). However, Moskal, Martin, and Laumon (2012) found that being a male motorcyclist was a factor that increased the risk of a crash. This suggests that there may more to the over-representation of male motorcyclists in crashes than just their greater number. Across many areas of life (e.g. gambling, financial, health/safety, and recreation), men engage in more risk-taking behaviours than women (Byrnes, Miller, & Scafer, 1999; Harris, Jenkins, & Glaser, 2006; Waldron, McCloskey, & Earle, 2005; Weber, Blais, & Betz, 2002). This is due, in part, to differences in their assessments of risk. Men perceive less risk in risky activities (Weber et al., 2002), while women have a higher perceived likelihood of negative outcomes, higher perceived severity of potential negative outcomes, and lower expectation of enjoyment from risky activities (Harris et al., 2006). Therefore, it is possible that males ride motorcycles in more of a risk-taking manner leading to an overrepresentation in motorcycle crashes. Further research would be needed to determine whether this is true.

The present findings contrast those of Lin and Kraus (2009), Villaveces et al. (2003) and Soderstrom et al. (1995) that motorcycle riders are more likely to have consumed alcohol prior to a crash than car drivers. Lin and Kraus (2009) noted that motorcycle riders are more vulnerable to the effects of alcohol on balance, motor coordination, and judgement. It is possible that most motorcyclists recognise this and avoid drinking and riding, which would explain the finding that crash-involved motorcyclists were less likely to have a BAC over the legal limit than car drivers. The lower likelihood of being over the legal BAC limit may have contributed to the finding that motorcyclists were less likely to be found at-fault in multiple vehicle crashes. The lower likelihood of being at-fault would also be due to the common errors of car drivers in multiple vehicle angle crashes involving motorcyclists at intersections – so-called looked-but-failed-to-see/inattentional blindness errors (Clabaux et al., 2012; Clarke, Ward, Bartle, & Truman, 2007; Crundall, Crundall, Clarke, & Shahar, 2012; Pai, 2009; Pammer, Sabadas, & Lentern, 2018).

Crash Characteristics

The crashes of motorcyclists were more likely to be single vehicle crashes (specifically roll over, left road – out of control and hit object/animal/pedestrian on road crashes) and were more common on weekends, during the afternoon, on sloping roads, on curved roads, on roads with speed limits of 50 and 80 km/h, during daylight hours, in dry weather and on dry roads compared to the crashes of car drivers.

Research by Wells et al. (2004) in Auckland, New Zealand also found that crash related injuries to motorcyclists occurred mainly in areas with a 50 km/h speed limit, during the day, and in fine weather. Motorcyclists would be more likely to be injured in crashes at lower speeds because they are less protected than car drivers. There is also more of a culture of riding motorcycles for leisure rather than practical transport (Jamson & Chorlton, 2009). This would explain why the crashes of motorcyclists were more common on weekends, during the afternoon, during daylight hours, in dry weather and on dry roads because they can choose suitable times and optimal conditions. Wells et al. (2004) also found that motorcyclists were mainly injured in urban zones, which differs from the present finding that the crashes of motorcyclists and car drivers were both evenly split between metropolitan and rural areas. The different results could be due to different geographical study locations.

The finding that motorcyclists were more likely to have single vehicle crashes suggests that they have more crashes precipitated by loss of control. Indeed, examination of the 2014 to 2016 data, for which greater crash type information was available, found that motorcyclists were overrepresented in left road – out of control, roll over and hit object/animal/pedestrian on road crashes. This would also explain the finding that their crashes were more common on sloping and curved roads, as these roads would be more likely to lead to a single motorcycle losing control. Research in Germany by Fredriksson and Sui (2016) also found that loss of control crashes are the most common motorcycle crash types leading to serious injury.

Injury Patterns and Severity

Motorcyclists had a higher level of injury severity than car drivers, spent longer in hospital, and were more likely to sustain injuries to multiple body regions. The injured regions for motorcyclists from most to least common were the extremities, external regions, the chest, the head/neck, the abdomen and facial regions. This differed slightly from drivers, with the injured regions from most to least common being external regions, the head/neck, the chest, the extremities, the abdomen and facial regions. There was evidence to suggest that injury severity for motorcyclists may be highest for left road – out of control and head on crashes. Finally, linear regression showed that older age, higher BAC and higher speed limit were predictive of higher severity of injury to crash-involved motorcyclists.

These findings are consistent with the findings of Van Eslande and Elvik (2012) that serious injuries occur with greater frequency for motorcyclists. They are also consistent with Lin and Kraus (2009) who found that motorcycle riders often sustain multiple injuries in a crash and the most common site of injury is to the lower extremities. Forman et al. (2012) also found that injuries to lower and upper extremities were most common for motorcyclists. Both the increased injury severity and the most common site of injury being to the extremities would be due to the unprotected nature of motorcycle riding. Extremities would be the first point of impact when a rider falls to the road or makes contact with a roadside barrier.

With regard to the regression findings, the relationship between older age and increased injury severity has been found for motorcyclists in other studies (Savolainen & Mannering, 2007) and would be due to the increased fragility that comes with older age. Older road users have a lower tolerance to physical trauma (Evans, 1988; Li, Braver, & Chen, 2003). The relationship between higher speed limits and increased injury severity would be due to increased travelling speed. Although the relationship between travelling speed and the risk of crashes and injuries has been demonstrated conclusively for cars (Kloeden, McLean, Moore, & Ponte, 1997; Elvik, Christensen, & Amundsen, 2004), similar research has not been conducted for motorcycles. This may be due to the greater difficulty associated with computer reconstruction of motorcycle crashes. However, the fact that motorcyclist speed profiles tend to involve higher speeds than other vehicles (Baldock et al., 2012) emphasises the need for speed enforcement on popular high speed recreational riding routes. Consistent with the present findings, alcohol use has previously been shown to be associated with higher risk of injury and increased injury severity in a crash (Nakahara et al., 2005; Rifaat et al., 2012; Savolainen & Mannering, 2007). This association is likely due to other risk-taking decisions that intoxicated riders may be more likely to make, such as speeding and not wearing a helmet or protective clothing. Finally, type of crash with two categories (single or multiple vehicle) was included in the regression analysis and shown not to have an effect on injury severity. However, it is likely that a more detailed crash type variable (e.g. right angle, rear end, etc.) or impact type variable (front, side, rear) would have an effect. This information was not available for all cases and so was not included as a variable in the regression analysis.

Potential Countermeasures to Improve Motorcycling Safety

Potential countermeasures for motorcycle crashes include an improved Graduated Licensing System (GLS), and improvements in infrastructure, vehicle technology and protective clothing. At the time of writing, most jurisdictions in Australia, including South Australia, are considering strengthening their existing motorcycle GLS. Injured motorcyclists were more likely to hold a learner permit than injured car drivers in the present study, which suggests an enhanced GLS (e.g. inclusion of on-road test of abilities for novice riders before they are allowed on the road, requirement that novice riders wear high visibility clothing) is warranted.

One GLS element recommended by Baldock (2018) is the requirement for novice riders to have a zero BAC. Currently, South Australia (along with Western Australia and the Northern Territory) does not require a zero BAC for novice riders, but does require it for novice drivers. Motorcyclists were less likely to have an illegal BAC than car drivers in the present study but the opposite has been found in other studies (Lin & Kraus, 2009; Villaveces et al., 2003; Soderstrom et al., 1995). Also, Moskal et al. (2012) demonstrated that alcohol is the largest risk factor for the crash involvement of motorcyclists. Alcohol consumption is known to affect the necessary skills for safe riding (balance, coordination and judgement) (Lin & Kraus, 2009) and the present study demonstrated that a higher BAC increased injury severity. Therefore, it is reasonable to recommend that a zero BAC for novice motorcyclists would be a beneficial way of strengthening the GLS in South Australia.

A report by Austroads (2016) recommended several road infrastructure-based crash prevention measures for motorcyclists. To reduce single vehicle/loss of control crashes, they recommended: improvements to the road surface (e.g. resurfacing) on curves, curve approaches and departures; improving and maintaining delineation and curve warning signage; lane widening and sealed shoulder widening on curves; and wide centre lines. To reduce multiple vehicle crashes at intersections, they recommended: providing sightlines at intersections to improve sight distances (or intersection warning signs or pavement markings if safe sight distances cannot be provided), separating movements at signalised intersections with designated right turn lanes, and protecting turning motorcycles with channelised right and auxiliary left turn lanes.

Advances in motorcycle technology are also likely to bring safety benefits. Ponte, Searson, Royals, and Anderson (2015) identified combined braking systems, traction control systems and anti-lock braking systems (ABS) as likely to be beneficial and claimed that if all motorcycles sold in South Australia in 2025 were fitted with ABS, the reduction in motorcycle crashes would be around 10 to 25%. Finally, encouraging the uptake of protective clothing is an important measure to reduce injury severity among crash-involved motorcyclists. In particular, an independent rating system could assist motorcyclists to make informed choices about which clothing provides superior protection (de Rome, Gibson, et al., 2012).

Study Limitations

The data only included crashes in which at least one participant had been admitted to hospital. The reason for this was that one of the central purposes of this study was to examine injury patterns and severity and the depth of detail required could only be obtained from detailed hospital admission records. However, a future study could include property-damage only and minor injury crashes (private doctor or hospital treated), as well as crashes in which the rider died at the scene.

Information on the clothing worn by crash-involved motorcyclists (i.e. protective or not) was not routinely collected by either the hospital or police. Consequently, this was not examined. Failure to wear protective clothing is an important factor in the risk and severity of injury to motorcyclists (de Rome et al., 2011) and would ideally be investigated in future research, particularly as a mitigating variable in a regression model to predict injury severity. Other factors that would be interesting to examine in relation to injury severity would be the engine size and type of bike (e.g. sports bike, dirt bike, road bike, cruiser) of crash-involved motorcycles, as well as vehicle age and safety technologies of both motorcycles and cars. Research by Brown et al. (2016) indicated that riders using sports motorcycles have greater odds of being involved in serious injury crashes than riders using other motorcycle types. Vehicle age and safety technologies may also influence the types of crashes that riders and drivers have. However, information on these factors was also not collected in the hospital or police data.

Conclusions

A key strength of this study was that detailed data from hospital records (e.g. injury severity for specific body regions) were linked to police-reported crash data and forensic blood tests for a large sample of injured riders of motorcycles and scooters. Wilson, Begg, and Samaranayaka (2012) have noted the lack of such published linkage studies for motorcycle crashes. These data provided a detailed picture of current crash and injury patterns for a high-risk road user group. A clear understanding of the current situation for motorcycle and scooter riders is necessary in order to facilitate future improvements in their safety.

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Notes

[1] A provisional licence is granted to an individual once they have fulfilled the requirements to progress from a learner permit. A probationary licence is granted after a period of licence suspension (or, in some cases, instead of licence suspension).

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