FACTORS ASSOCIATED WITH MOTORCYCLE CRASHES IN WESTERN AUSTRALIA: 2005 TO 2011

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Abstract
This report presents the results of an investigation into motorcycle crashes occurring in Western Australia (WA) between 2005 and 2011. Trends in all motorcycle crash rates over the period were described and factors associated with serious injury and other severity types of motorcycle crashes at intersections were identified. Factors such as rider demographics, surface of the road, types of crash, intersection layout, traffic control signals, and posted speed limit were examined accordingly.

Over the 2005 to 2011 period, 8,902 motorcycle riders involving in 8,750 crashes were identified from the WA crash database. The motorcycle crash rate gradually decreased from almost 200 motorcycle crashes to 150 motorcycle crashes per 10,000 registered motorcycles between 2005 and 2011, despite a steady increase in the number of registered motorcycles over this period. A similar trend was found for the serious injury motorcycle crash rate (which included hospitalisations and fatalities). However, the serious injury motorcycle crash rate was consistently around 4 times higher than that of all motor vehicles.

Of motorcycle crashes at intersections, a great proportion of crashes were found on Fridays, peak hours, fine weather, sign controlled intersections, T-junctions, straight, sealed and dry roads, and daylight. Post speed limits at 50 and 60 km/hr accounted for more than 70% of the total motorcycle crashes at intersections. More than 40% of these crashes were right angle/ right turn through crashes and more than a quarter led to a serious injury crash. Males accounted for the majority of motorcycle crashes at intersections, and most riders aged between 16-44 years old.

For motorcycle crashes at intersections, factors associated with serious injury crashes (fatal and hospitalisation) were identified. Motorcycle crashes at intersections which occurred on Thursdays were frequently resulting in a serious injury compared with crashes on Sundays. Head-on/right angle/right turn crashes and hit object/animal/pedestrian crashes were significantly associated with an increased risk of serious injury compared with rear end crashes. Non-collision motorcycle crashes were associated with a lower risk of serious injury and the presence of traffic lights was also significantly associated with a decreased risk of serious injury. Motorcycle crashes which occurred at night or under dark lighting conditions were frequently leading to a serious injury. In contrast, motorcyclists less frequently sustained a serious injury if the crash occurred during peak traffic hours, on wet or curved roads.

The results provide Main Roads Western Australia and other road safety organisations with preliminary information about potential strategies to reduce road trauma among motorcyclists in Western Australia.

Keywords
Motorcycle safety; intersection safety; serious injury crash; Toward Zero strategy

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EXECUTIVE SUMMARY

Motorcyclists accounted for less than 6% of licensed vehicle users in Western Australia (WA) in 2008, but represented 15% of road deaths (Johnson, Brooks et al. 2008). This is alarming as the number of motorcycles registered in Australia between 2006 and 2010 increased by 48.5% (ABS, 2011). A recent report indicated that a substantial portion of motorcycle crashes in WA occurred at intersections and roundabouts, leading to a significant number of serious injuries and deaths (C-MARC, 2011). This may reflect the fact that the current road system presents potential hazards to motorcyclists, and there is an urgent need to better protect these vulnerable road users. While a recent report evaluating the effect of the WA Black Spot Program on motorcycle crashes showed some promising benefits for motorcyclists (Meuleners, Hendrie et al. 2011), it is likely that more could be done to further reduce casualties from motorcycle crashes. The results of this report will provide valuable information to road authorities about the risk factors for motorcycle crashes at intersections in WA. It is anticipated that this information will be used when developing new or upgrading existing road infrastructure in WA, to make intersections safer for motorcyclists.

A population based retrospective study was undertaken to determine temporal, road, crash and rider characteristics for motorcycle crashes at intersections in WA from January 1, 2005 to December 31, 2011. Police reported crash data from the Integrated Road Information System (IRIS) maintained by Main Roads WA, was obtained. The specific objectives of this study were to:

- Describe trends in motorcycle crash rates in WA between 2005 and 2011;
- Compare risk factors associated with motorcycle crashes at intersections with motorcycle crashes at mid-blocks; and
- Determine risk factors associated with serious injury motorcycle crashes (fatal and hospitalisation) at intersections.

The major findings from the evaluation are summarised below.

Overall

Between 2005 and 2011 there were 8,902 motorcycle riders involved in a crash (8,750 crashes), which accounted for 3.2% of total crashes over the study period. The average annual crash rate was 165.4 per 10,000 registered motorcycles. The number of registered motorcycles increased from 53,051 in 2005 to 99,392 in 2011. The average annual serious injury crash rates (crashes leading to hospitalisations or fatalities) for total motor vehicle and motorcycles were 13.4 and 48.4 per 10,000 registered motor vehicles/motorcycles. Approximately 50% of motorcycle crashes occurred at intersections, of which 26.5% were fatal or serious injury crashes.

Motorcycle crash rates in WA (per 10,000 registered motorcycles) gradually decreased between 2005 and 2011, despite a steady increase in the number of registered motorcycles over the same period. There were substantial differences in temporal factors, road characteristics, and crash types and severities between motorcycle crashes at intersections and mid-blocks, even though a similar distribution in the rider's characteristics and police attendance were found.

Factors associated with serious injury (fatal and hospitalisation) motorcycle crashes at intersections were identified. Compared to motorcycle crashes at intersections on Sundays, serious injury crashes were less on Thursdays. If a motorcycle crashed at an intersection, the odds of serious injury was 2 times higher for head-on/right angle/right turn through and hit object/animal/pedestrian crashes compared with rear-end crashes. Traffic signal controls at intersections were significantly associated with a decreased odd of serious injury compared to intersections that had no traffic control or sign. Motorcyclists had a 20% increased odds of being involved in a serious injury crash if they crashed at night, but a 10% decreased odds of serious injury if the crash was during peak hours. Wet roads and curved road alignment were all significantly associated with decreased odds of serious injury if motorcyclists crashed at intersections. Low lighting at intersections, on the other hand, was associated with increased odds of involving a serious injury.

Discussion

Motorcycle crash rates and serious injury crash rates in WA (per 10,000 registered motorcycles) decreased gradually between 2005 and 2011, despite a steady and

significant increase in the number of registered motorcycles over the study period. However, the serious injury motorcycle crash rate was almost 4 times higher than the rate for total motor vehicles over this period. In addition, the decreased number of crashes in 2009 may be related to a change in crash reporting requirements implemented in mid-2008. This should be considered when interpreting the findings in this report.

Based on WA crash records, motorcycle crashes at intersections were found to frequently occur under certain temporal and road-related factors. These factors may play a significant role in the crash risks and should be further investigated. As the number of motorcycle crashes at intersections was similar to the number at mid-blocks, the higher proportion of crashes at mid-blocks involving in a serious injury should be noted. Factors associated with the severity of injury for motorcycle crashes at mid-blocks would need to be identified to further improve riders' safety.

Results indicated that motorcycle-intersection crashes occurring on Thursdays frequently resulted in a serious injury compared to crashes which occurred on a Sunday. Further investigation would be required to explain this finding. Time of day (peak hours) and weather conditions (wet roads) are not easily modifiable risk factors. However, other traffic management devices, such as red light speed cameras, could be implemented at risky intersections to reduce travelling speeds for all road users at all times of the day.

Not surprisingly, the results found that among motorcycle crashes at intersections, crash types such as head-on, right angle/right turn through crashes and hit object/animal/pedestrian crashes were significantly associated with higher odds of causing serious injury compared to rear-end crashes. The odd of being seriously injured in a motorcycle crash could be reduced if the intersection was controlled by traffic signals. Strategies targeting crash types such as right angle and right turn through crashes or better roadside barriers around intersections may prevent such severe outcomes. Traffic management strategies that have been used for motorcycle safety in other countries, such as two stage right turns and exclusive motorcycle lanes, may also reduce the opportunity for conflict between motorcyclists and other road users, thus improving intersection safety.

Intersections with curved or wet roads had a protective effect for those involved in motorcycle crashes. This may reflect the fact that riders or other road users tend to be more cautious and slow down when approaching intersections under these conditions. Poor lighting conditions at intersections may pose difficulties for other road users in seeing motorcycles, which could explain why a statistically significant association was found between darker lighting and serious injury motorcycle crashes. Several studies have highlighted the role of the conspicuousness of motorcycle riders in crashes. The findings of this report may substantiate these findings.

A limitation of this study was the lack of complete data available for key variables, such as helmet use and alcohol involvement, both of which have been reported to have strong correlations with crash severity. In addition, the cross-sectional nature of the study means the data cannot be used to confirm causal-relationships. Despite these limitations, this report provides Main Roads WA and other road safety organisations with reliable, objective information that can be used to devise strategies to improve road safety for motorcyclists.

Conclusion and Recommendations

In conclusion, this study found that motorcycle crashes in WA accounted for a small proportion of total crashes, even though the number of motorcycle registrations increased significantly over the year of 2005-2011. Although the overall crash rate and serious injury crash rate for motorcycles generally decreased over time, the consistently high severity crash rate for motorcycles, which was around 4 times higher than that for all motor vehicle crashes, highlights a need for interventions targeted specifically at motorcyclists. Given that intersection safety and vulnerable road users are the priorities of the Toward Zero strategy, factors associated with motorcycle crashes at intersections should be addressed. While an increase in the number of motorcycles inevitably impacts other road users, it also challenges WA road authorities to devise a safer environment and road system for this growing population.

Recommendations include:

- Regular examination of motorcycle crash trends and identification of “black spots” for motorcyclists;
- Consideration of the differences between intersections and mid-blocks when developing strategies targeting motorcycle safety;
- Development of new interventions and initiatives such as better design of roads, signs and signals, which can separate motorcyclists and drivers on the roads, and better lighting at intersections to avoid traffic conflicts between motorcyclists and other road users; and
- Improvement of crash recording/reporting systems to ensure the completeness of crash data.

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1. INTRODUCTION

Globally, approximately 180,000 motorcyclists die on the roads each year (Naci, Chisholm et al. 2009). In Australia, motorcyclist deaths account for 12% of total road deaths (Naci, Chisholm et al. 2009). However, recent research found that the percentage of motorcyclists killed in road crashes among all road users is increasing, indicating that motorcycle riders may be over-represented in serious injury and fatal crashes in Australia (Haworth 2012). In 2008, motorcyclists accounted for less than 6% of total registered vehicle users, but represented 15% of total road deaths in WA (Johnson, Brooks et al. 2008). This is of great concern as the number of motorcycles registered in Australia increased by 48.5% from 2006 to 2010 (ABS 2011), highlighting the need to better protect these vulnerable road users. While initiatives targeting black spots in WA have showed some promising safety benefits for motorcyclists (Meuleners, Hendrie et al. 2011), further interventions are required to improve motorcycle safety.

A recent report found that a substantial portion of motorcycle crashes in WA occurred at intersections and roundabouts, leading to a significant number of serious injuries and deaths (C-MARC 2011). This finding suggests that the current road system presents certain hazards for motorcyclists and that current road designs may not be suitable for an increasing motorcycle population. For instance, motorcyclists are less conspicuous at intersections, especially when many vehicles are present (Pai 2011). Evidence suggests that the current road system does not assist drivers in seeing and/or giving way to riders, increasing the risk of collisions (Clarke, Ward et al. 2004; MAIDS 2004). In addition, ~~manoeuvring~~ traversing curves is very different for motorcyclists compared to car drivers whereby motorcyclists tend ~~have~~ to take a different line and work to balance the motorcycle due to the complex interaction of forces between the motorcycle and the road (C-MARC 2011).

Previous studies have identified environmental factors associated with motorcycle crashes. In Singapore, motorcyclists were found to be over-involved in crashes at signalised intersections (Haque, Chin et al. 2010). Turning manoeuvres at intersections as well as failure of drivers to notice, or accurately judge the speed/distance of an oncoming motorcycle were major risk factors for multi-vehicle motorcycle crashes at intersections (Haque, Chin et al. 2012). Factors such as speed,

lane width, number of lanes, shoulder width and land use (commercial area or not) were also found to be significantly associated with motorcycle crashes at non-signalised intersections in Malaysia (Harnen, Umar et al. 2003). Moreover, increases in the numbers of motorcycles entering an intersection as well as the numbers of other vehicles on major roads, were also found to be predictors of motorcycle crashes at non-signalised intersections in Malaysia (Harnen, Umar et al. 2003). A recent study conducted in Taiwan found that the risk of fatal crashes at intersections was higher for motorcyclists than other motor vehicles (Li, Doong et al. 2009). It should be noted that the majority of these studies examining risk factors for motorcycle crashes come from countries where motorcycles are the primary form of transportation (Hsu, Sadullah et al. 2003). These findings may not be generalisable to an Australian setting where motorcyclists only constitute a small proportion of road users.

Few studies examining risk factors for motorcycle crashes have been conducted in developed countries, including Australia. Existing evidence suggests that the type of roadside safety barriers, time and day of crash, weather conditions, road surface, speed and drink driving are all associated with fatal motorcycle crashes in Australia and New Zealand (Jama, Grzebieta et al. 2011). Previous research also found that motorcyclists were more often at fault than other road users in multi-vehicle crashes (Clarke, Ward et al. 2004; Johnson, Brooks et al. 2008). Improving the safety of motorcyclists is in line with the goals of the new WA road safety strategy "*Towards Zero*", which aims to build a tolerant road system, accounting for road user error without serious consequences (Office of Road Safety 2009).

1.1. Aims and objectives

The overall aim of this study was to describe the epidemiology of motorcycle crashes at intersections in WA from 2005 to 2011, based on temporal, road, crash-related and rider characteristics.

The specific objectives were to:

1. Describe trends in motorcycle crashes in WA between 2005 and 2011;

2. Compare risk factors associated with motorcycle crashes at intersections with motorcycle crashes at mid-blocks; and
3. Determine risk factors associated with serious injury motorcycle crashes (fatal and hospitalisation) at intersections.

1.2. Significance

The number of motorcyclists on WA roads is increasing. This study will provide valuable information to road authorities about the risk factors for motorcycle crashes at intersections in WA. It is anticipated that this information will be used when developing new or upgrading existing road infrastructure in WA, to make intersections safer for motorcyclists. Ultimately, this may reduce the incidence of crashes involving motorcyclists at intersections in WA.

2. METHODS

2.1. Study Design

A population based retrospective study using police reported crash data was undertaken to determine factors such as temporal, road, crash and rider characteristics for motorcycle crashes at intersections in Perth, WA from January 1, 2005 to December 31, 2011.

2.2. Data Collection

Police-reported crash data was obtained from the Integrated Road Information System (IRIS), which is maintained by Main Roads Western Australia. Crash data in which the rider was a motorcyclist was extracted from January 1, 2005 to December 31, 2011.

2.2.1. Integrated Road Information System (IRIS)

The Integrated Information System (IRIS) database contains detailed information on the characteristics of those involved in road crashes, including crash circumstances, police reported injury, vehicle characteristics and road information related to the crash location from January 1985 to the present.

The definition of a crash used throughout this report is the definition used by the Road Safety Council in its annual publication "Reported Road Crashes in Western Australia" (Legge et al. 2006). A crash is "*any apparently unpremeditated collision reported to the police which resulted from the movement of at least one road vehicle on a road open to and used by the public and involving death or injury to any person, or property damages*". In WA during the study period, it was mandatory to report a crash to the police if a person was injured or if property damage exceeded $1,000 before July 1, 2008 and $3,000 from July 1, 2008.

All motorcycle crashes were identified via the utility type (type of vehicle or traffic unit) with "8" referring to a motorcycle in the IRIS database. Only the rider of the motorcycle (identifiable via "RDUSER"=1) were included in analyses. As motorcycles only constitutes of a small proportion of all registered vehicles (3-5%, see table 3.1), and only a few crashes involved more than one motorcycle, a crash

involving in multiple motorcycle riders (more than one motorcycle crashed) were counted as multiple motorcycle crashes. A serious injury crash in this report is defined as "*a road crash which resulted in a person being killed or hospitalised*". Crashes coded as "medical treatment only", "property damage (major)" and "property damage (minor)" were grouped as minor injury crashes.

2.3. Methodological Issues in Motorcycle Crash Research

Lin and Kraus (2008) have identified a series of methodological issues that should be considered when undertaking motorcycle crash research. Some of these issues, including estimation of the population at risk, quality of crash data sources, and completeness of information on important variables such as alcohol consumption, use of helmet, crash severity, and crash speeds which may impact on the study results and are discussed in detail below.

2.3.1. Estimation of Population at Risk

When estimating the incidence of crashes or crash-related injury, the total population over a specified time period in the region is often used to represent the population at risk of motorcycle crash/injury (the denominator). As motorcycles only comprised 6% of all registered motor vehicles in Australia in 2008 (Johnson, Brooks et al. 2008), the use of total population data may considerably overestimate the population at risk. Even though the number of registered motorcycles, licensed riders and vehicle kilometres travelled are better surrogate measures than the total population, they have their own limitations which should be considered accordingly and rates should be interpreted with caution. Ideally, the best denominator (population at risk) for estimating crash risks should take into account the number of persons as well as the distance/time exposed to traffic (exposure). However, such data is usually unavailable in current surveillance systems or not collected due to difficulty in measurements. The current study uses the number of registered motorcycles in WA as a surrogate of population at risk, which is extracted from the motor vehicle census conducted by the Australian Bureau of Statistics between 2005 and 2011.

2.3.2. Quality of Crash Databases

Death registry data, hospital records, police reports and a combination of other data sources are commonly used for crash research. Nevertheless, information from these sources has their own limitations. Police reports on the other hand, are relatively comprehensive in terms of the collection of data on crash risk factors such as vehicle information, rider demographics and road environment. Due to the unique geography of WA, crashes leading to minor injury or property damage only can be reported privately by vehicle occupants involved in the crash through the Online Crash Reporting Facility (OCRF). This may lead to differences in the quality of data obtained from police reported and non-police reported crashes in WA. Using a combination of various data sources may increase the validity and reliability of data. However, the differing data formats used and the lack of unique identifiers may make linking different databases difficult.

The identification of reported crashes involving a motorcycle is quite accurate in WA crash databases. However, the validity and reliability of the reported injury severity is a common problem in crash databases (Farmer 2003). Fatal and hospitalisation crashes are easily identifiable and measurable compared with minor injury and property damage only crashes, even though the severity in crash records may not always match the severity reported in corresponding hospital records (Rosman and Knuiman 1994). The main issue for fatal crashes is the differentials in defining the time interval (from crash to death) for a crash-related fatality, which may vary from 28 days to 30 days among different jurisdictions/countries. Hospital records may not always specify the external cause of injury, increasing the difficulty in identifying crash-related hospitalisations (Langley, Davie et al. 2007). Crash databases usually have good consistency with other databases for fatal and hospitalisation crashes, as these severe outcomes are more likely to be reported (Barancik and Fife 1985; Aptel, Salmi et al. 1999). Minor injury on the other hand, may not have such consistency and it is often arbitrary to group an occupant into medical treatment required or property damage only (Farmer 2003; Sciortino, Vassar et al. 2005). Due to these issues, this report uses a binary outcome to specify whether the motorcycle crash involved a serious injury (fatal or hospitalisation) or not.

2.3.3. Completeness of Crash Information

As mentioned above, in WA, when the outcome of a crash does not involve serious injury or fatality it can be reported via the OCRF. However, the information may not be as complete as for crashes reported by police officers. The completeness of information obtained from the OCRF is unknown but worthy of investigation.

Given police reports often record a variety of information on crash risk factors, such as rider demographics (age and gender), vehicle information (year of vehicle), behavioural factors (BAC level, helmet usage) and road characteristics (posted speed limit), such information is often incomplete in the database. Therefore, some important variables, such as rider age were unable to be investigated in this report due to a high proportion of missing data (over one-third).

2.4. Statistical Analysis

Trends in all motorcycle crash rates in WA between 2005 and 2011 were examined. The distributions of characteristics for motorcycle crashes by crash location (intersections vs. mid-blocks) were also described. For those motorcycle crashes which occurred at intersections, characteristics were examined in terms of crash severity (serious injury vs. minor injury) using Chi-square or Fisher's exact tests if 25% of the cells had expected counts less than 5.

Logistic regression models were used to identify the most significant risk factors for motorcycle crashes at intersections which were involved in a serious injury (fatality or hospitalisation). Factors that contributed to the robustness of the model (LR test), or were significantly associated with motorcycle crashes at intersections ($p<0.05$) were retained in the final model. Factors with more than 10% missing values were not included in the models. The SAS (9.2) data package was used for all data extraction and statistical analysis.

3. RESULTS

The results of this report are divided into three sections. The first section briefly summarises trends in all motorcycle crash rates in WA between 2005 and 2011. The second section contains an analysis of factors associated with motorcycle crashes occurring at intersections, compared to mid-blocks. The final section contains an analysis of factors associated with serious injury motorcycle crashes (fatal and hospitalisation) occurring at intersections.

3.1. Trends in Motorcycle Crash Rates in WA

Between 2005 and 2011, there were 8,902 motorcycles involved in 8,750 crashes, which accounted for 3.2% of the total number of crashes (Table 3.1). Although the proportions of motorcycle crashes were similar across study period (2.7%~3.8%), the number of motorcycle crashes increased slightly over time, from 1,058 in 2005 to 1,498 in 2011. Over the same period, motorcycle registrations dramatically increased from approximately 53,000 (3.5% of motor vehicle registrations) in 2005 to over 99,000 (5.2%) in 2011, representing an 87% increase.

Despite an increase in the number of motorcyclists involved in crashes, motorcycle crash rates (per 10,000 registered motorcycles) decreased over time. The number of motorcycle crashes per 10,000 was nearly 200 in 2005, but dropped to 144 in 2009 and then slightly increased to 150 by 2011(Figure 3.1). A similar trend was observed for the total motor vehicle crash rate (per 10,000 registered motor vehicles). The serious injury crash rates for motor vehicles and motorcycles (per 10,000 registered motor vehicles/motorcycles) also decreased over time. However, the serious injury crash rate for motorcycles was almost 4 times higher than that for total motor vehicles (Figure 3.2).

Table 3.1 Trends in motorcycle crashes between 2005 and 2011 in WA

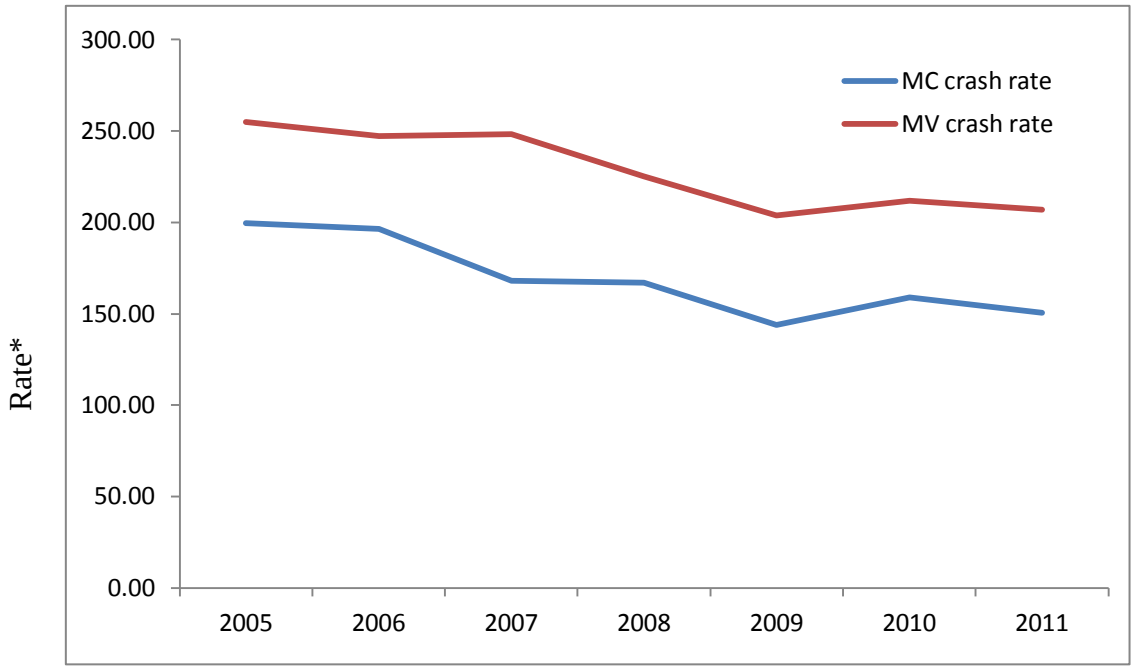
Year	No. MV[1] Crashes	No. MC[2] crashes	(%)	MV[1] serious injury crashes	MC[2] serious injury crashes	(%)	No. registered MV[1]	No. registered MC[2]	(%)	MV[1] crash rate*	MC[2] crash rate *	MV[1] serious injury crash rate*	MC[2] serious injury crash rate*
2005	38985	1058	(2.71)	2539	320	(12.6)	1529615	53051	(3.5)	254.87	199.43	16.6	60.3
2006	39563	1172	(2.96)	2305	359	(15.6)	1600566	59675	(3.7)	247.18	196.40	14.4	60.2
2007	41635	1143	(2.75)	2403	340	(14.1)	1676495	68031	(4.1)	248.35	168.01	14.3	50.0
2008	39309	1286	(3.27)	2464	404	(16.4)	1746579	77010	(4.4)	225.06	166.99	14.1	52.5
2009	37232	1253	(3.37)	2183	365	(16.7)	1828346	87044	(4.8)	203.64	143.95	11.9	41.9
2010	39634	1492	(3.76)	2207	403	(18.3)	1870068	93901	(5.0)	211.94	158.89	11.8	42.9
2011	39596	1498	(3.78)	2163	411	(19.0)	1912739	99392	(5.2)	207.01	150.72	11.3	41.4
Total	**275954**	**8902**	**(3.23)**	**16264**	**2602**	**(16.0)**	**12164408**	**538104**	**(4.4)**	**226.85**	**165.43**	**13.4**	**48.4**

*crash rates were estimated by per 10,000 registered MV/MC vehicle

[1]: all motor vehicles (including motorcycles); [2]: motorcycle (multiple motorcycles in a crash were counted separately)

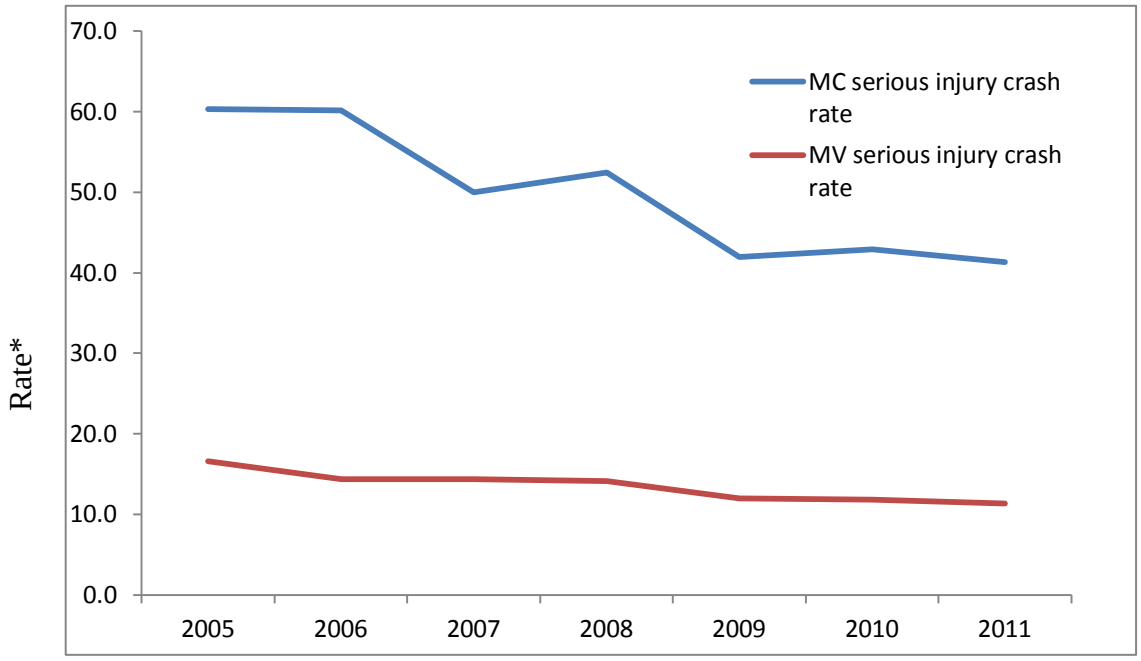
Note: The number of registered vehicles is based on data from 31 March 2005 to 31 March 2010. In 2011, the number of registered vehicles is based on data from 31 January 2011 to 31 January 2012.

Figure 3.1 Crash rates* for total motor vehicle (MV) and motorcycle (MC) crashes in WA between 2005 and 2011



*: Rates were estimated per 10,000 registered MV/MC

Figure 3.2 Serious injury crash rates* for total motor vehicle (MV) and motorcycle (MC) crashes in WA between 2005 and 2011



*: Rates were estimated per 10,000 registered MV/MC

3.2. The Distribution of Motorcycle Crashes at Intersections and Mid-Blocks

3.2.1. Factors for Motorcycle Crashes at Intersections

Of the 8902 motorcycle crashes 4,503 (50.6%) occurred at an intersection, 4,309 at mid-blocks (48.4%) and 90 (1%) occurred at other locations such as public access roads/areas and were excluded from this study. Table 3.2 shows the distribution of motorcycle crashes across a variety of factors, including temporal, road, crash and rider characteristics, by crash location (an intersection or a mid-block). This should be interpreted with caution due to missing values.

Motorcycle crashes at intersections were unevenly distributed across most factors of interest. A large proportion of crashes were found on Fridays, which accounted for more than 17% of motorcycle crashes. Wednesdays and Thursdays also constituted more than 30% of crashes, whereas crashes on Saturdays and Sundays only represented 12% and 10%, respectively. More than 50% of crashes occurred at peak hours (6-10am; 4-8pm) and only 8% occurred at night (10pm-6am). The majority of these crashes occurred when the weather was clear (87%).

Approximately 40% of motorcycle crashes occurred at an intersection which was only controlled by road sign, such as a stop or give way sign. Another 27% occurred at intersections with a traffic signal controller and the remaining 32% occurred at intersections without any form of control (no signs or traffic signals). About half of these crashes were located at a T-junction (51.2%). The large majority of crashes occurred on a straight road (77.4%), on sealed roads (99.7%), dry conditions (88.7%), during daylight (73.1%) Posted speed limits of 50 and 60 km/hr accounted for more than 70% of the total motorcycle crashes at intersections, however information was missing for more than 25% of motorcycle crashes.

More than 40% of motorcycle crashes were right angle/ right turn through crashes. Rear-end and non-collision crashes accounted for 21% and 17%, respectively. In terms of crash severity, more than a quarter of crashes (26%) led to a serious injury crash. Males accounted for the majority of motorcycle crashes at intersections and most riders aged between 16-44 years old (16-24:26%; 25-34: 25%; 35-44: 22%). It should be noted that more than 3,000 crash records had no age information. Most

riders wore a protection device (helmet) at the time of the crash (93.8%); however almost one quarter of crash records had no such information recorded. Police attended about half of these crashes (49.0%).

Motorcycle crashes at mid-blocks were more frequent on Fridays (17%), Saturdays (16%) and Sundays (16%), but less frequent on Mondays (12%). The distribution of these crashes by time of day, weather, road layout, road alignment, road surface, road conditions, lighting, rider's gender and age, protection usage and police attendance were similar to the distribution of motorcycle crashes at intersections (see Table 3.2). In contrast, a greater percentage of motorcycle crashes at mid-blocks occurred in high posted speed limits (90-110km/h). More sideswipe, non-collision and hit pedestrian/animal/object crashes were also identified among motorcycle crashes at mid-blocks. When examining the distribution of motorcycle crashes by severity of crash and intersections and mid-blocks, a greater percentage of serious injury crashes occurred at mid-blocks (32% at mid-blocks vs. 27% at intersections).

Table 3.2 Characteristics of motorcycle crashes occurring at intersections and mid-blocks in WA, 2005-2011

	Intersection		Mid-block	
	n	%	n	%
All motorcycle crashes (N=8,812)	4,503	51.1	4,309	48.9
TEMPORAL FACTORS				
Day of week				
Monday	595	13.2	500	11.6
Tuesday	656	14.6	534	12.4
Wednesday	714	15.9	599	13.9
Thursday	688	15.3	615	14.3
Friday	804	17.9	716	16.6
Saturday	561	12.5	674	15.6
Sunday	485	10.8	671	15.6
Time of day (missing=70)				
Off-peak (10am-4pm; 8-10pm)	1,765	39.5	1,839	43.1
Peak (6-10am;4pm-8pm)	2,373	53.1	2,060	48.3
Night (10pm-6am)	335	7.5	370	8.7
Weather (missing=456)				
Clear	3,733	87.2	3,623	88.9
Other (e.g. Raining, fog, overcast, smoke or dust)	549	12.8	451	11.1
ROAD FACTORS				
Traffic control (missing=20)				
Traffic lights	1,217	27.0	17	0.4
Road sign	1,851	41.1	56	1.3
No control	1,434	31.9	4,217	98.3
Road layout (missing=4,306)				
3-way intersection (T-junction)	2,268	51.2	39	52.0
4-way intersection or more than 4-way intersection	1,437	32.4	20	26.7
Roundabout	726	16.4	16	21.3
Road alignment (missing=590)				
Curved	932	22.6	1,110	27.1
Straight	3,200	77.4	2,980	72.9
Road surface (missing=98)				
Sealed	4,451	99.7	4,174	98.2
Unsealed	14	0.3	75	1.8
Road condition (missing=169)				
Wet	497	11.3	371	8.8
Dry	3,913	88.7	3,862	91.2
Lighting (missing=245)				
High (daylight)	3,190	73.1	3,193	76.0
Moderate (dawn/dusk/dark - street lights on)	1,102	25.2	844	20.1
Low (dark – street lights off or not provided)	74	1.7	164	3.9
Posted speed limit(km/hr) (missing=2,262)				
<=40	40	1.2	58	1.8
50	1,027	31.5	1,032	31.3
60	1,299	39.9	904	27.4
70	541	16.6	327	9.9
80	246	7.6	262	8.0
90	35	1.1	104	3.2
100	31	1.0	294	8.9
110	37	1.1	313	9.5

CRASH CHARACTERISTICS				
Crash type (missing=455)				
Rear end	941	21.1	679	17.4
Head-on/Right angle/Right turn through	1,900	42.7	659	16.9
Sideswipe	506	11.4	847	21.7
Non-collision	748	16.8	929	23.8
Hit pedestrian/animal/object	356	8.0	792	20.3
Severity				
Serious injury (fatal and hospitalisation)	1,193	26.5	1,368	31.8
Minor (medical and PDO)	3,310	73.5	2,941	68.3
RIDER CHARACTERISTICS				
Gender (missing=346)				
Female	415	9.6	386	9.3
Male	3,918	90.4	3,747	90.7
Age (missing=3054)				
<12	1	0.0	2	0.1
12~15	13	0.5	18	0.6
16~24	726	25.7	701	23.9
25~34	701	24.8	793	27.1
35~44	629	22.2	663	22.6
45~54	522	18.5	473	16.2
55~64	191	6.8	230	7.9
>=65	46	1.6	49	1.7
Protection (missing=2,220)				
Worn	3,144	93.8	3,020	93.2
Not worn	207	6.2	221	6.8
Police attendance (missing=31)				
No	2,289	51.0	2,172	50.6
Yes	2,198	49.0	2,122	49.4

3.3. Factors Associated with Serious Injury Motorcycle Crashes at Intersections

3.3.1. Risk Factors for Serious Injury Motorcycle Crashes at Intersections

There were 4,503 motorcycle crashes at WA intersections between 2005 and 2011 and more than a quarter of these crashes were serious injury crashes (a fatality or hospitalisation crash). The distribution of various factors by injury severity is shown in Table 3.4. As a proportion (>15%) of crash records had no information on posted speed limit, age and helmet use, these variables were not included in the severity analysis. Road layout was included in the analysis as most missing values were attributed to mid-block crashes.

There was a significant difference in the severity of injury by day of the week ($p=0.006$). While Fridays appeared to be the day that had the most serious injury and minor injury motorcycle crashes, a greater proportion of serious injury motorcycle crashes was found on Sundays. Time of day was significantly associated with serious injury outcomes for motorcycle crashes at intersections ($p<0.0001$), particularly during night hours. However, off-peak and peak times accounted for 90% of serious injuries resulting from motorcycle crashes at intersections. No statistical difference in severity of injury by weather conditions was observed ($p=0.57$).

The presence of traffic controls at an intersection was significantly associated with severity of injury ($p<0.0001$). The proportion of serious injury crashes was higher at intersections without any form of traffic control (39%), than intersections with traffic controls (29%). Intersections with only traffic signs, regardless of injury severity, accounted for more than 40% of motorcycle crashes. Road layout was also significantly associated with injury severity ($p<0.0001$). Three way intersections accounted for more than 58% and 48% of serious and minor injuries resulting from motorcycle crashes at intersections, respectively. Road alignment, surface and lighting (moderate and low lighting were combined due to small sample sizes) were significantly associated with increased odds of serious injury due to a motorcycle-intersection crash (all p-values <= 0.05). Road condition (wet or dry), on the other hand, was not significantly related to crash severity ($p=0.1$).

Crash type was also significantly associated with injury severity for motorcycle crashes at intersections ($p<0.0001$). Regardless of injury severity, head-on/right angle/right turn through crashes accounted for the majority of motorcycle crashes at intersections. Injury severity did not differ by gender ($p=0.09$). Police attended the majority of motorcycle crashes at intersections when there was a serious injury, but only attended 34% of minor injury motorcycle crashes, indicating a significant difference in police attendance by severity of injury for motorcycle crashes at intersections ($p<0.0001$).

Table 3.3 Characteristics of motorcycle crashes occurring at intersections by crash severity, WA 2005-2011

	Crash severity				Chi-square Test
	Serious Injury		Minor Injury		
	n	%	n	%	
Motorcycle crashes at intersections (N=4,503)	1193	26.5	3,310	73.5	
TEMPORAL FACTORS					
Day of week					
Monday	145	12.2	450	13.6	$\chi2$=18.0,
Tuesday	169	14.2	487	14.7	p=0.006
Wednesday	174	14.6	540	16.3	
Thursday	162	13.6	526	15.9	
Friday	235	19.7	569	17.2	
Saturday	151	12.7	410	12.4	
Sunday	157	13.2	328	9.9	
Time of day (missing=30)					
Off-peak (10am-4pm; 8-10pm)	470	39.8	1,295	39.3	$\chi2$=22.9,
Peak (6-10am;4pm-8pm)	587	49.7	1,786	54.3	p<0.0001
Night (10pm-6am)	124	10.5	211	6.4	
Weather (missing=221)					
Clear	1,009	87.7	2,724	87.0	$\chi2$=0.3,
Other (e.g. Raining, fog, overcast, smoke or dust)	142	12.3	407	13.0	p=0.57
ROAD FACTORS					
Traffic control (missing=1)					
Traffic lights	224	18.8	993	30.0	$\chi2$=68.4,
Road sign	502	42.1	1,349	40.8	p<0.0001
No control	467	39.2	967	29.2	
Road layout (missing=72)					
3-way Intersection (T-junction)	688	58.4	1,580	48.6	$\chi2$=33.9,
4-way intersection or more than 4-way intersection	319	27.1	1,118	34.4	p<0.0001
Roundabout	171	14.5	555	17.1	
Road Alignment (missing=371)					
Curved	221	19.3	711	23.8	$\chi2$=9.7,
Straight	925	80.7	2,275	76.2	p=0.002
Road surface (missing=38)					
Sealed	1,187	100.0	3,264	99.6	$\chi2$=5.1,
Unsealed	0	0.0	14	0.4	p=0.03
Road condition (missing=93)					
Wet	118	10.0	379	11.7	$\chi2$=2.7, p=0.1
Dry	1,064	90.0	2,849	88.3	
Lighting (missing=137)					
High (daylight)	775	66.2	2,415	75.6	$\chi2$=37.8,
Low and Moderate (other than daylight)	395	33.8	781	24.4	p<0.0001
CRASH CHARACTERISTICS					
Crash type (missing=52)					
Rear end	112	9.4	829	25.4	$\chi2$=290.9,
Head-on/Right angle/Right turn through	673	56.7	1,227	37.6	p<0.0001
Sideswipe	67	5.6	439	13.5	
Non-collision	175	14.7	573	17.6	
Hit pedestrian/animal/object	160	13.5	196	6.0	
RIDER CHARACTERISTICS					
Gender (missing=170)					
Female	99	8.4	316	10.0	$\chi2$=2.8,
Male	1,086	91.7	2,832	90.0	p=0.09
Police attendance (missing=16)					
No	117	9.9	2172	65.8	$\chi2$=1095.7,
Yes	1,071	90.2	1,127	34.2	p<0.0001

3.3.2. Factors Associated with Serious Injury Motorcycle Crashes at Intersections

Table 3.5 shows the factors associated with serious injury motorcycle crashes at intersections in WA using a logistic regression model. Significant risk factors for serious injury crashes were; day of the week, time of day, type of traffic control at intersection, type of crash, road conditions, and lighting at the site of the crash (Table 3.5). For motorcycle crashes at intersections, crashes that occurred on Thursdays less frequently resulted in a serious injury compared to those which occurred on Sundays. Likewise, crashes that occurred at night (10pm~6am) were 20% more frequently to result in a serious injury, whereas crashes during peak hours were 10% less frequently to result in a serious injury compared to crashes which occurred during off-peak hours. Results also showed that when traffic signals were present at the intersection the odds of sustaining a serious injury was 20% lower than intersections with no traffic controls (no signs or traffic signals). Compared to rear-end crashes, head-on/right angle/right turn through and hit object/animal/pedestrian crashes had significantly higher odds of serious injury (OR: 1.9~2.4). There was a 50% less odds of serious injury if a motorcycle-intersection crash was non-collision crashes compared with rear-end crashes and 20-30% less frequently to be a serious injury crash if it occurred on curved and wet roads compared to straight and dry roads, respectively. Finally, the odds of a motorcycle-intersection crash resulting in serious injury was 20% higher in low and moderate lighting conditions than high light conditions (daylight).

Table 3.4 Risk factors associated with serious injury motorcycle crashes at intersections

Effect	Adjusted OR	95% CI		P p-value
Day of week				
Sunday*				
Monday	0.9	0.74	1.09	0.27
Tuesday	0.9	0.78	1.14	0.54
Wednesday	1.0	0.80	1.14	0.61
Thursday	0.8	0.69	0.99	0.04
Friday	1.1	0.93	1.30	0.25
Saturday	1.0	0.79	1.17	0.68
Time of day				
Off-peak(10am-4pm; 8-10pm)*				
Night (10pm-6am)	1.2	1.02	1.52	0.03
Peak(6-10am; 4pm-8pm)	0.9	0.75	0.96	0.01
Traffic control				
No control*				
Traffic lights	0.8	0.73	0.94	0.004
Road Sign	0.9	0.82	1.01	0.09
Crash type				
Rear end*				
Head-on/Right angle/Right turn through crash	2.4	1.94	2.97	<0.0001
Sideswipe	0.9	0.77	1.10	0.38
Non-collision	0.5	0.39	0.63	<0.0001
Hit object /animal/pedestrian	1.9	1.65	2.14	<0.0001
Road alignment				
Straight*				
Curved	0.8	0.67	0.99	0.04
Road condition				
Dry*				
Wet	0.7	0.54	0.89	0.004
Lighting				
High *				
Low & Moderate	1.3	1.91	1.55	0.009

*****indicates the reference group

4. DISCUSSION

This report presented an epidemiological analysis of motorcycle crashes occurring between 2005 and 2011 in Western Australia. Motorcycle crash rates (per thousand registered motorcycles) decreased between 2005 and 2011, despite a steady and significant increase in the number of registered motorcycles over this period. Although a similar trend was found for the serious injury motorcycle crash rate, it was consistently four times higher than the rate for all crashes.

Most motorcycle crash distributions stratified by crash locations (intersection vs. mid-block) were similar in patterns. However differences in day of week, posted speed limits and crash types should be taken into account when developing safety strategies for intersections as well as mid-blocks. However, the higher proportion of crashes which occurred at mid-blocks involving a serious injury warrants further research.

Risk factors associated with increased odds of a serious injury in motorcycle crashes at intersections included head-on/right angle/right turn through and hit object/animal/pedestrian crashes (vs. rear-end crashes), night crashes (vs. non-peak hours), straight (vs. curved) and dry roads (vs. wet). Motorcycle crashes which occurred on Thursdays and at intersections with traffic signals (vs. no control) had lower odds for a serious injury.

The number of motor vehicle and motorcycle crashes in WA both dropped in 2009 which may be related to changes in crash reporting requirements implemented in mid-2008. While there was no change in reporting requirements for crashes involving injury, the value of property damage crashes increased from $1,000 before July 1, 2008 to $3,000 after July 1, 2008. In addition, the inclusion of “injury crashes not requiring medical treatment” into the “medical” group by the Insurance Commission of Western Australia may have had an impact on the grouping of crashes recorded in 2010, but this would need to be substantiated by further investigation. These issues should be considered when interpreting the results of this study.

Despite a steady increase in number of motorcycle crashes over the study period, motorcycle crash rates (per thousand registered motorcycles) gradually decreased. Nevertheless, motorcycle riders are less protected and more vulnerable than drivers as evidenced by a four times increased serious injury crash rate compared to the rate for all motor vehicles. To achieve the national goal of a 40% reduction in serious injuries and fatalities on the roads, these findings indicate a need for initiatives or interventions that will prevent motorcycle crashes or reduce the severity of injury in the event of a crash (Office of Road Safety 2009). A regular examination of motorcycle crash trends is recommended to monitor motorcycle safety in WA.

This study only described the crash patterns at intersections as well as at mid-blocks. Even so, the crash patterns identified are compatible to results from other studies conducted in South East Asian countries where motorcycles are the dominant means of transportation. This is despite differences in the traffic profile of Western Australia. For example, Harnen et al. (2003) found that increased intersection traffic flow was associated with an increased risk of motorcycle crashes which is similar to the findings of this report identifying motorcycles are more frequently crashed at intersections during peak hours. Haque et al. (2012) also commented that motorcycle riders paid more attention while driving on wet road surfaces, especially at night when light levels were low, which supports the findings of this report. The differences in crash pattern by intersections and mid-blocks may provide some essential information for future road safety strategies for motorcyclists.

The results of this study found that crash types such as head-on/right angle/right turn through and hit object/animal/pedestrian motorcycle crashes were significantly associated with more severe injury in intersection crashes. This is consistent with previous literature (Preusser, Williams et al. 1995; Peek-Asa and Kraus 1996; Wang and Abdel-Aty 2007; Daniello and Gabler 2011). Surprisingly, the odds of being seriously injured from a non-collision motorcycle crash (most were “loss of control” crashes, which were categorised as “single vehicle crash”) was lower than for a rear-end crash. Although previous studies have suggested that single vehicle crashes were associated with a higher risk of being severely injured (Shankar and Mannering 1996; Stella, Sprivulis et al. 2001; Chen, Ivers et al. 2009), it is possible that non-collision crashes were combined with run-off-road or hit object crashes in those

analyses. Nevertheless, it is clear that preventing hit object/animal/pedestrian and head-on/right angle/right turn through crashes at intersections has the potential for reducing motorcyclist casualties.

It has been found that red light cameras with or without speeding detection at intersections can reduce head-on/right angle/right turn through crashes (Aeron-Thomas and Hess 2005; Budd, Scully et al. 2011). Strategies that have been used to manage motorcycle safety in Asian countries may also be useful to mange motorcycle safety in WA. For instance, exclusive motorcycle lanes, setback-waiting spaces for motorcycles at signalised intersections, and two-stage left-turn (right-turn in Australia) traffic control countermeasures (Sohadi, Mackay et al. 2000; Hsu, Sadullah et al. 2003) may help reduce conflicts between motorcycles and other vehicles at intersections in Australia. Roadside barriers better designed or modified to ensure motorcyclist safety through innovations such as The Barriacel Motorcycle Crash Attenuating Device (MCAD) (Highway Engineering Australia, 2011) may also reduce the risk of motorcycles hitting objects or pedestrians around intersections (Jama, Grzebieta et al. 2011).

Traffic flow at intersections is often better managed by traffic signals or signage compared to intersections without any controls. Traffic signals provide cues that raise a road users' awareness of potential traffic conflicts and alerts them to change their behaviour accordingly (Elvik and Vaa 2004). This may explain the finding of the reduced odds of being seriously injured in a motorcycle crash if traffic lights were present at the intersection, which is similar to what has been found in other studies examining intersection safety (Quddus, Noland et al. 2002; de Lapparent 2006; Pai and Saleh 2008). Moreover, a greater proportion of motorcycle crashes occurred at intersections with road signs, as well as T-junctions, which should be a concern for road authorities and should be further investigated.

Previous studies have reported that factors such as wet roads and travelling during peak traffic hours may be associated with reduced crash severity due to motorists driving with extra precaution or slowing down (Golob, Recker et al. 2004; Haque, Chin et al. 2012). While it is believed that travelling during peak traffic hours may increase the risk of crashing, the injuries associated with those crashes are likely to

be less severe due to low travel speeds during these hours (Quddus, Wang et al. 2010). It may be a misconception that wet roads increase the risk of losing control for motorcyclists. A previous study suggested that rainfall itself increased crash risk rather than the lingering wet roads after rainfall (Andrey and Yagar 1993). The results of the current study support this finding. Nevertheless, weather conditions and time of day are not easily modifiable risk factors. However, other traffic management strategies, such as red light speed cameras could be implemented at risky intersections to reduce travelling speeds for all road users at all times of the day.

Many recent studies have highlighted the role of conspicuousness of motorcycle riders in crashes (Wells, Mullin et al. 2004; Pai 2011; Haque, Chin et al. 2012) as well as road lighting at the time of the crash (Sullivan and Flannagan 2007). These findings are consistent with the current study which found that motorcycle crashes at intersections with poor lighting or low brightness were associated with increased risk of severe injury. It has also been reported that one of the two most common reasons for motorcycles colliding with other vehicles was that they were not seen by other vehicle users (Espié, Bekiaris et al. 2010). Therefore, the findings of this report may suggest that there is a need to improve lighting at intersections in order to increase motorcyclist conspicuousness. Information on protecting clothing should also be collected in the database to clarify this issue.

A limitation of this study was the incomplete data for key variables which have been previously found to be associated with serious injury motorcycle crashes, such as helmet use (Rutledge and Stutts 1993; Heldt, Renner et al. 2012), alcohol involvement (Kasantikul, Ouellet et al. 2005) and rider age. Including variables with a high proportion of missing values in statistical models may decrease the sample size dramatically and reduce the power to detect significant associations (Hawthorne and Elliott 2005). Incomplete data on rider age also posed difficulties for describing this vulnerable group. A better design crash recording/reporting system and a series of training sessions in crash reporting for police officers may improve the completeness of this data in the future. This study was also limited by its cross-sectional design. Although associations between risk factors and motorcycle crashes were identified, cross-sectional studies cannot be used to confirm causal relationships (Rothman, Greenland et al. 2008). Further studies investigating motorcycle crashes

using stronger epidemiological designs, such as a cohort study, would allow cause-effect relationships to be determined and interventions to be developed accordingly. Finally, the results could be biased in this report as information on exposure data is not available. Collecting exposure information in future studies would help estimate the incidence/rate of motorcycle crashes.

5. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the results of this study found that motorcycle crashes in WA only accounted for a small proportion of total number of crashes. Given that intersection safety and vulnerable road users are priorities of the "*Toward Zero*" strategy, factors associated with motorcycle crashes at intersections, particularly those relating to serious injuries should be addressed. This is especially important as the number of motorcycle registrations has increased dramatically over the last few years in WA. While the increase in motorcyclists inevitably impacts other road users, it also challenges WA road authorities to devise a safer environment and road system for this growing population.

Recommendations

This project examined trends in motorcycle crashes in Western Australia between 2005 and 2011, as well as factors associated with intersection crashes and serious injury motorcycle crashes at intersections. Despite study limitations, the results are useful for road authorities to improve intersection safety, particularly for motorcyclists.

Recommendations include:

- Regular examination of motorcycle crash trends and identification of "black spots" for motorcyclists;
- Consideration of the differences between intersections and mid-blocks when developing strategies targeting motorcycle safety;
- Development of new interventions and initiatives, such as better design of roads (e.g. exclusive lane for motorcyclists at busy intersections), better lighting at intersections, and improved signs and signals to avoid traffic conflicts between motorcyclists and other road users; and

- Improvement of crash recording/reporting systems to ensure the completeness of crash data.

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