Finding evidence-based strategies to improve motorcycle safety: A case-control study on serious injury crashes in Victoria

Allen[a], T., Day[a], L., Lenne[a], M., Symmons[b], M., Newstead[a], S., Hillard[a], P., McClure[a], R.

[a] Monash University Accident Research Centre, [b] School of Applied Media and Social Sciences, Monash University

Abstract

The popularity of motorcycling combined with rider vulnerability necessitates a high priority on motorcycle safety. The most recent comprehensive case-control study of motorcycle crashes in Australia was conducted 15 years ago, when the road environment was dramatically different. The aim of this study was to provide a contemporary evidence base to inform motorcycle safety. The study employs a case-control design with two components: 1) with the rider as the unit of the analysis, and 2) with the road infrastructure as the unit of analysis. Participants are injured riders admitted to hospital (cases), or riders who pass the crash site (controls). Each case investigation included a questionnaire-interview, inspection of crash site and motorcycle, and inspection of a control site. This paper reports on cases only. The study has recruited 75 cases to date. 25% of case riders were aged under 30yrs, and one-third reported a total riding experience of less than 3 years. 60% of crashes involved another road user. The most common self-reported crash scenario was another vehicle turning into the path of the rider (31%). 68% of cases occurred in urban areas and one-quarter of crashes occurred on a Sunday or public holiday. Half of crashes occurred at intersections, and 21% occurred at a corner or bend. Calculations indicated that the rider was exceeding the speed limit in 27% of those cases where travel speed could be estimated. Case data so far shows a number of key differences from previous studies. When combined with control data at the completion of collection, this study will provide new evidence-based recommendations relating to safe roads, safe speeds, safe road users and safe vehicles.

Introduction

Motorcycles are a significant part of Australia's transport future, with motorcycle registrations doubling in the past 15 years. Although trends in motorcycle fatality rates (relative to the number of registered motorcycles) are declining, motorcycle fatalities comprise an increasing proportion of all road deaths due to increased motorcycling and the dramatic improvements in motor car safety over recent decades (Haworth, 2012). The vulnerability of motorcyclists is reflected in hospital admission rates in 2005-6 that were 10 times higher than those of passenger cars per 10,000 registered vehicles (Berry and Harrison, 2008). Therefore future road safety strategies aimed at reducing rates of serious injury to motorcyclists should place a high priority on reducing the incidence of crashes.

Serious injury motorcycle crashes involve a complex interaction between the road environment, the vehicle(s) and the road user(s). While studies on motorcycle crashes have been conducted recently outside of Australia, caution must be taken in generalising those findings for local road safety initiatives (Haworth, 2012). The last comprehensive case-control study investigating characteristics and causative factors of serious injury motorcycle crashes in Australia was conducted more than 15 years ago (Haworth et al., 1997). Since that time, the road environment has changed dramatically, including a 44% increase in the number of all registered vehicles (Australian Bureau of Statistics, 1997 & 2012), and significant changes to road infrastructure, speed limits, licencing rules, and motorcycle characteristics. A more recent study in Victoria (Stephan et al., 2008) provided valuable information on characteristics of fatal crashes that did (and did not) involve excessive or inappropriate speed. The report also demonstrated the need for a case-control study to better understand factors related to serious (non-fatal) motorcycle crashes, to support new evidence-based motorcycle safety initiatives. The purpose of this study is therefore to address some of these knowledge gaps, with a focus on three main areas: road infrastructure (safe roads), travel speed (safe speeds) and rider related factors (safe road users).

This study employs a population based case-control design which includes an in-depth crash investigation component (Day et al., 2013). This paper presents a preliminary case series analysis of the in-depth crash investigation component from the first 75 recruited cases. Those aspects of this study relevant to the case-series data to date are detailed here. Our preliminary results are discussed in relation to case reports from of the Victorian study conducted over 15 years ago (Haworth et al., 1997) and the more recent Victorian study on fatal crashes (Stephan et al., 2008).

Methods

Participants and recruitment

Cases were 75 motorcycle riders who were injured in a motorcycle crash and admitted to one of 15 Victorian hospitals (10 metropolitan, 5 regional). Study hospitals accounted for 78% of motorcycle crash admissions in the state of Victoria in the past 3 years (unpublished data from the Victorian Injury Surveillance Unit). The key eligibility criteria for cases were:

- Rider of powered-two wheeler involved in a crash (not pillion)
- Crash occurred on a public road in Victoria
- Rider aged over 18 years
- Rider admitted to a hospital ward or short stay unit (not emergency presentation only)
- Crash occurred between the hours of 6am and midnight

Riders meeting all eligibility criteria were recruited by a hospital-based research nurse and invited to participate in a questionnaire-based interview. If an eligible rider was discharged prior to being approached, a letter of invitation was posted to them with the option of completing the questionnaire by telephone. Once the questionnaire was completed, the study crash investigator was contacted and provided with the necessary details to immediately commence an inspection of the motorcycle and crash scene.

Measurement modules

The measurement modules relevant to the in-depth crash investigation were:

1) Case rider questionnaire: Information relating to the rider, crash circumstances of trip factors, and motorcycle details.
2) Crash site inspection: Information on characteristics of the road environment, reconstruction of crash, and assessment of contributing factors.
3) Motorcycle inspection: Assessment of damage for crash reconstruction, motorcycle pre-crash condition (eg. tyres, brakes, steering), presence of safety features.
4) Travel speed estimation: Uses measures from modules 2 & 3 to estimate travel speed prior to crash event.

A subset of variables from these modules is reported here using a "safe systems" structure (see Table 1). All study variables will form part of the case-control analysis to be performed at completion of data collection in 2014. For a complete description of the study design and detail on all variables measured see Day et al. (2013).

Table 1. Study modules used for this case report using Safe Systems structure

	Safe Roads	Safe Speeds	Safe Road Users	Safe Vehicles
Case Rider Questionnaire	x		x	
Crash Site Inspection	x		x	
Motorcycle Inspection		x	x	x
Travel Speed Estimation		x		

Safe Roads: features of the road environment

Aspects relevant to the road environment were captured in the crash site inspection and rider interview. Site-based inspections used a structured data collection tool based on established protocols of others (Bellion, 1997; Fildes et al., 2008; Hillard, et al., 2005). Measurements included road type and geometry, intersection type, traffic control devices, speed limit and road surface condition. The rider questionnaire included both structured and open questions on possible contributors of the road environment to the crash, such as presence of any visual obstructions, traffic density, weather conditions and condition of the road surface.

Safe Speeds: estimation of travel speed

Speed-related information was obtained from both the site and motorcycle inspections. Travel speed just prior to the crash was estimated using established protocols (Bellion, 1997; Fildes et al., 2008). This included estimation of impact speed using vehicle deformation data and motorcycle specifications (eg. change in wheelbase) and/or rider dynamics (eg. slide distance, tumble distance), as well as estimation of velocity change prior to impact, using evidence at the crash site (eg. road surface characteristics, coefficient of friction, length of skid profiles and marks where available). The crash investigator provided an assessment of rider travel speed with respect to both the posted speed limit (ie. exceeding limit or not) and the conditions at the time of the incident (ie. appropriate speed).

Safe Road Users: rider factors and involvement of other road users

Information in relation to the road user(s) was captured in both the rider interview and site and motorcycle inspections. The rider questionnaire included open questions about the possible contribution of the rider and other road user(s) to the crash. It also included structured questions about the rider such as age, riding experience, previous training and licence history. Riding experience reported here was defined as the number of years since gaining a motorcycle licence, excluding any years where he/she reported they stopped riding for more than 12 months. Motorcycle riders were consulted on the content of questions as part of questionnaire development. The site and motorcycle inspections formed part of an objective assessment on potential contributions of road users to the crash, including the rider, other vehicles and pedestrians. The study site inspector and crash investigator was an experienced motorcyclist and received training on crash investigation and site inspection techniques from 3 experienced crash investigators.

Safe Vehicles: characteristics of case motorcycles

Information about the motorcycles was collected from both the rider interview and the motorcycle inspection. Details included type of motorcycle, engine capacity and presence of any safety features such as anti-lock brakes (ABS) was also recorded.

The study has been approved by the Monash University Human Research Ethics Committee (CF11/0989 – 2011000482), and the relevant hospital ethics committees.

Results

A total of 760 patients screened at study hospitals were riders of powered two-wheelers. Of those patients, 190 met all study eligibility criteria. Approximately 40% of eligible patients were approached by a research nurse. Of those riders approached, 76% consented to participate. The case series data reported here is from the first 75 recruited riders.

Safe Roads: features of the road environment

Table 2. Road types at crash locations

	Urban	Rural	All roads
X-Intersection	13	4	17
Y-Intersection	2	2	4
T-Intersection	13	1	14
Not intersection: straight	19	4	23
Not intersection: curve	4	13	17
TOTAL	**51**	**24**	**75**

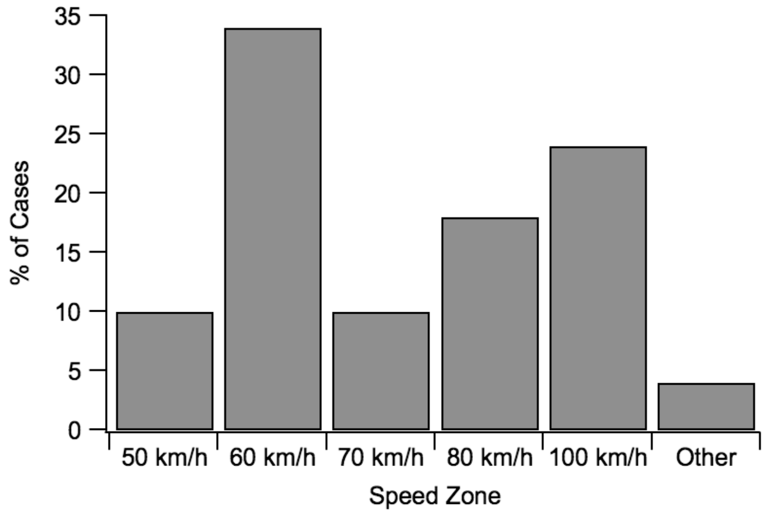
Of those crashes investigated 68% occurred in urban areas, with a small number of freeway crashes (3%). Slightly more than half of those crashes in urban areas occurred at intersections (55%), while in rural areas 54% of crashes occurred at a curve or bend.

In 11 cases (15%) the road surface was reported by the rider as contributing to the crash. In 4 cases (5%) an animal on the road was the initiating event in the crash (all in rural areas), while in 2 cases (3%) weather factors contributed to the crash.

Safe Speeds: estimation of travel speed

The most common speed zones at crash sites were 60 km/h (34%) and 100 km/h (24%), (see Figure 1). An estimation of rider travel speed prior to the crash was possible in 37 cases (49%). Calculations indicated that in 27% of these the rider was exceeding the speed limit.

Figure 1. Speed zones at crash sites



Safe Road Users: rider factors and involvement of other road users

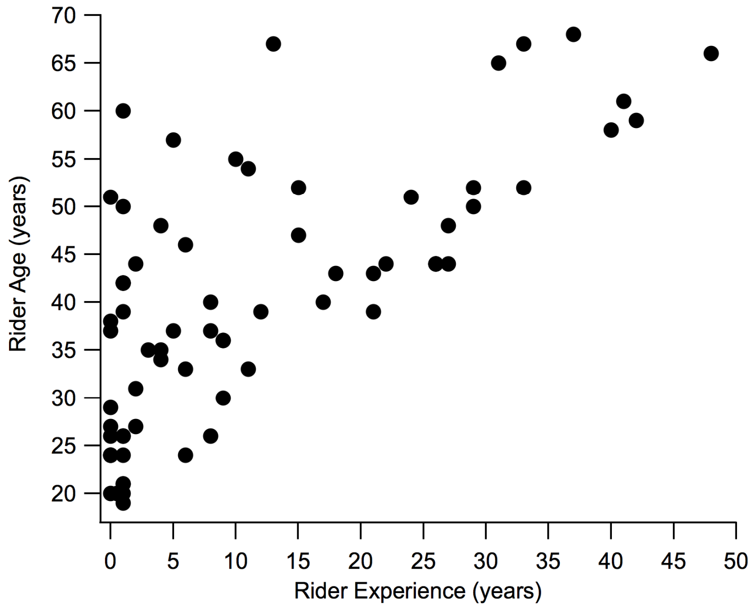
Single vehicle crashes made up 40% of cases, while 60% of crashes involved another vehicle(s). Over two-thirds of multi-vehicle crashes occurred at an intersection (see Table 3). For multi-vehicle crashes the most common crash scenario was another vehicle turning into the path of the motorcyclist (69%). For single-vehicle crashes almost half occurred at a curve or bend. Preliminary analysis of the crash scene and motorcycle inspection data suggest that in ~70% of single vehicle crashes a misjudgement or control error on the part of the rider was a contributing factor. One quarter of crashes occurred on a Sunday or public holiday.

Table 3. Single and Multi-vehicle crashes versus road type

	Single-vehicle	**Multi-vehicle**	**All crashes**
Intersection	5	30	**35**
Mid-block straight	11	12	**23**
Mid-block curve	14	3	**17**
TOTAL	**30**	**45**	**75**

Two-thirds of cases involved riders aged 35 years or older, and one-third of riders were 45 years or older. More than one-third of riders had less than 3 years of motorcycle riding experience while one quarter of riders had more than 20 years of riding experience. A low level of rider experience (< 3 licence years) was not restricted to younger riders, indicating some riders obtained their licence at an older age or were returning riders (see Figure 2).

Figure 2: Case rider age plotted against riding experience (licence years)



Safe Vehicles: characteristics of case motorcycles

The most common motorcycle types were cruisers (31%) and sports bikes (27%). Half of case motorcycles had an engine capacity of 750cc or greater, and less than a quarter of motorcycles were less than 260cc (Table 4).

Two case motorcycles (3%) were fitted with an anti-lock braking system (ABS).

Table 4. Engine capacity and type of case motorcycles

	< 260 cc	261-749cc	750-1249cc	> 1249cc	All capacities
Scooter / Moped	5	-	-		**5**
Standard Road	-	4	3		**7**
Sports Tourer	-	5	5		**10**
Sports / Race Replica	4	4	10	2	**20**
Cruiser	3	3	7	10	**23**
Other	5	3	1	1	**10**
TOTAL	**17**	**19**	**26**	**13**	**75**

Discussion

Safe Roads: features of the road environment

The current study found a similar proportion of crashes occurred at intersections compared to Haworth et al. (1997), (47% compared with 49%). When comparing intersection type (X, Y and T-intersections) the proportions were also very similar. It is however important to note the difference in study area, with the earlier study investigating cases within Melbourne metropolitan area, whereas the current study included cases within the state of Victoria including a larger proportion of rural areas.

A much smaller proportion of crashes occurred on curves compared to that reported by Haworth et al. (23% compared with 70%). This may partly be explained by differing definitions of a curve – as the earlier study also appeared to include turns made at intersections. If the current study includes all cases where the rider was turning (including intersections) our proportion increases to 29%, which is still well below that of the earlier study. The completion of the case-control aspect of this study will provide more valuable information on the possible risk factors associated with the road environment and therefore point towards effective countermeasures.

The highest proportion of crashes occurred on a Sunday or public holiday in the current study (compared with Friday for the Haworth 1997 study). This may partly reflect our inclusion of cases from non-metropolitan areas, where recreational riders are likely to ride on weekends. The study of fatal motorcycle crashes by Stephan et al. (2008) also reported Sunday as having highest crash frequency. These more recent findings may suggest that the proportion of motorcyclists riding for leisure and recreation has increased over recent years in Victoria.

Safe Speeds: estimation of travel speed

A much smaller proportion of crashes occurred in 60 km/h zones (34% compared with 65%) and a greater proportion of crashes in 100 km/h zones compared to Haworth et al. (24% compared with 16%). This may reflect either a) the greater proportion of rural roads in the geographical area of the current study (explaining both findings), b) a change to speed zones in many urban residential roads (from 60 to 50) since the earlier study, or c) the inclusion of cases with low injury severity crashes in the earlier study.

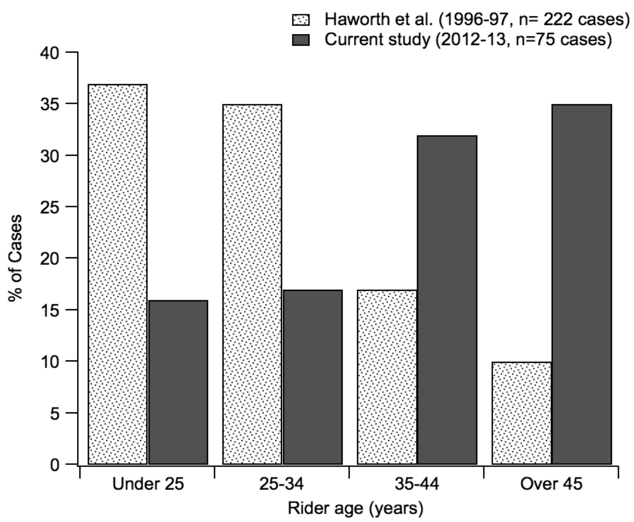
The proportion of cases judged to be exceeding the speed limit is similar between the current study (27%) and the earlier study (23%) conducted by Haworth et al. (1997). It should be noted that the earlier study included both low severity injury and fatal crashes in their sample population, making a direct comparison not possible. The study of fatal motorcycle crashes by Stephan et al. (2008) reported that 49% of cases (that could be classified) either definitely or probably involved excessive speed. The potential role of excessive speed determined from fatal crash investigations of course cannot be translated to more common serious injury motorcycle crashes. The case-control aspect of the current study will shed light on whether or not travel speed influences relative risk of crash, and the interaction of travel speed with other factors such as rider experience.

Safe Road Users: rider factors and involvement of other road users

The number of crashes involving another vehicle is similar between two studies (60% compared with 67%). A greater proportion of multi-vehicle crashes occurred at intersections in the current study compared to Haworth et al. (67% compared with 53%). This cannot be explained by the difference in study geographic area, given the current study included crashes occurring outside the Melbourne metropolitan area where intersections are much less frequent.

The distribution of rider ages amongst cases is vastly different compared to that of Haworth (See Figure 3. This may be partly due to differences in inclusion criteria between the two studies (including age restrictions and geographical area). However, analysis of hospital admission data between 1995 and 2012 showed that while mean age has always been slightly higher for admissions to regional versus metropolitan hospitals (by ~ 1 year), there has been a gradual increase in mean age of motorcyclists admitted to all Victorian hospitals from 29 years in 1995 to 35 years in 2012 (source: VAED). This suggests that the age of injured riders has increased over time regardless of crash location. Whether or not rider age influences relative crash risk will be determined by the case-control component of the current study. An interesting question relates to the relative contributions of age and experience to reducing crash risk in motorcyclists – this may be answerable in the current study due to the presence of older riders with a small number of years riding experience (see Figure 2) – allowing separation of the influences of age and experience.

Figure 3. Case rider age distribution between Haworth et al. (1997) and current study



Safe Vehicles: characteristics of case motorcycles

Engine capacity of case motorcycles showed a smaller proportion of motorcycles with capacity < 260cc compared to findings of Haworth et al. (23% compared with 35%). The higher proportion of motorcycles with larger capacity was present for motorcycles with capacities of 260-749cc (25% compared with 20%) as well as capacities over 750cc (52% compared with 45%). This may reflect the older age of case riders in the current study compared to Haworth et al., providing riders with legal access to larger capacity motorcycles, and/or the introduction of LAMS in 2008 (Learner assisted motorcycle scheme), which permits novice motorcyclists to ride a selection of motorcycles with capacities exceeding 250cc. Alternatively there may be a popularity trend towards larger motorcycles such as cruisers, which were the most common motorcycle type in cases of the current study.

Vehicle safety systems such as ABS have the potential to reduce motorcycle crash risk, particularly given the greater difficulty in avoiding a crash for two-wheeled vehicles with reduced stability compared to passenger cars. This notion is supported by findings of both Haworth et al. and the current study to date in relation to frequency of crashes in which the rider control and braking errors contributed to the crash (and likely severity of injury). A recent study in the United States reported that the fatality rate was 37% lower for ABS-fitted motorcycles compared to the same model without ABS fitted (Teoh, 2011). Availability of ABS on popular motorcycle models has lagged behind that of passenger cars, but is now much more available than it was 15 years ago. The very small number of case motorcycles that were fitted with ABS can be explained in part by the age of Victoria's motorcycle fleet, with 60% of registered motorcycles being at least 6 years old, and 35% being at least 11 years old (Australian Bureau of StatisticsB 2012). Other possibilities include safety features being a low priority in riders' purchasing decisions (Christmas et al., 2009) and/or there is an under-representation of motorcyclists riding bikes fitted with anti-lock brakes (ABS), which would suggest either a protective effect of this technology or a link between more conservative riders and ABS-fitted bikes. The question of whether ABS reduces risk of serious injury crashes will be more definitively addressed at the completion of the case-control study, provided there are sufficient numbers of motorcycles with ABS for the analysis.

Study Limitations

This is a case-series report based on a subset of all measured variables from the first recruited 75 injured riders from a case-control study. Limitations exist when analysing case-series data without control data. At study completion we anticipate over 200 cases will have been collected and the inclusion of control data for both road infrastructure and rider-related factors. This will provide more valuable information on relative risk of factors related to road environment, rider-related factors and travel speed.

A relatively small proportion of eligible case riders have been approached, which reduces confidence that the case population is representative of all seriously injured riders. This is partly due to the challenges of approaching recently injured riders in the hospital environment where patient treatment remains the highest priority, as well as availability of research nurses within normal working hours. One potential bias may be a greater representation of more seriously injured riders, with less seriously injured riders being discharged from hospital more quickly (ie. before a research nurse has had the opportunity to approach).

Investigation of crash sites and motorcycles in the current case-control study often involved time delays before assessment of crash scenes compared to dedicated in-depth studies. Crash investigation did not commence until an eligible rider had been approached and consented, which was sometimes several days after the crash, particularly for more seriously injured riders who were not fit to be approached immediately. These delays were minimised using a notification system from research nurses that reached the crash investigator within hours of a case being recruited.

To date, there has been a low proportion of crashes for which motorcycle travel speed could be accurately estimated (49%). This proportion is not dissimilar to that reported by Stephan et al. (2008) for determining the involvement of excessive speed (57% of cases). A primary reason in the current study was a lack of evidence at the scene to provide an objective estimate (eg. absence of skid marks or evidence of where crash event was initiated). This was not necessarily related to delays between the crash and attendance at the site. A second reason was the unavailability of the motorcycle for inspection of impact damage (~29% of cases), usually due to challenges locating the motorcycle or making contact with the person in possession. The relatively low percentage of cases where travel speed could be estimated is expected to improve at study completion, as some calculations were not completed at the time of this paper.

Conclusion

This case-series report highlights some key differences to the case data reported by Haworth et al. (1997), with the proportion of crashes occurring on curves (less compared to earlier study) and rider age (older compared to earlier study) showing the greatest differences. However, more detailed analysis taking account of differences in study areas, road type definitions, and case injury severity would be required before these differences could be confirmed.

The findings from completed case series are likely to identify potential areas for improving motorcycle safety in all key areas of safer systems.

However, the case-control analysis at the completion of this study will provide more definitive indication of risk factors and subsequent strategies for improving motorcycle safety (Table 5).

Table 5: Summary of study implications using Safe Systems approach

Safe Roads	**Safe road users & Safe speeds**	**Safe Vehicles**
Completion of case-control study will provide insight into what features of roads (eg. intersection type, road surface condition) influence crash risk	Case data suggests effective future safety strategies should focus on all road users, including "look but don't see" phenomenon amongst other road users.	Case-control study may help test whether ABS-equipped motorcycles provide benefits in reducing risk of a serious injury crash.
	Case-control data will provide greater insight into possible safety benefits related to rider-related factors (eg. experience, training, travel speed)	

Acknowledgments

The study is funded by an Australian Research Council Linkage Project Grant and is funded and/or supported by the following Linkage Partner Organisations: VicRoads, the Transport Accident Commission, the Victorian Department of Justice, Victoria Police, and the Victorian Automobile Chamber of Commerce. We thank the motorcyclists who gave their time generously and provided welcome advice on the study design and questionnaires. Peter Bellion (Victoria Police) provided advice on speed estimation methods for the cases. Mark Stevenson, Michael Fitzharris and members of the ANCIS study team (Monash University) provided invaluable advice on the study design, questionnaire items and feasibility issues based on their previous experience. VicRoads staff assisted with finalising the methods for control recruitment, and organising the motorcyclist workshops. Angela Clapperton provided hospital admission data from the Victorian Admitted Episodes Dataset (VAED) cited in the discussion. We are most grateful for the support of the following hospitals for case screening and recruitment: The Alfred Hospital, Royal Melbourne Hospital, Austin Hospital, Ballarat Base Hospital, Bendigo Hospital, Box Hill Hospital, Dandenong Hospital, Geelong Hospital, Goulburn Valley Hospital, Latrobe Regional Hospital, Maroondah Hospital, Monash Medical Centre, Northern Hospital, and Frankston Hospital.

References

Australian Bureau of Statistics (Oct 1997). *Motor Vehicle Census, Australia*

Australian Bureau of Statistics (Dec 2012). *Motor Vehicle Census, Australia*

Bellion, P. (1997). Project Y.A.M. (Yaw analysis methodology) vehicle testing and findings - Victoria police, accident investigation section, *SAE technical paper* 970955. 1997, doi:10.4271/970955.

Berry, J. G. and Harrison, J. E. (2008), *Serious injury due to land transport accidents, Australia, 2005–06*, Injury Research and Statistics Series Number 42, Australian Institute of Health and Welfare, Canberra http://www.nisu.flinders.edu.au/pubs/reports/2008/injcat113.pdf

Christmas, S., Young, D., Cookson, R., & Cuerden, R. (2009). *Passion, performance, practicality: motorcyclists' motivations and attitudes to safety.* Transport Research Laboratory. Published project report PPR442. http://www.trl.co.uk/online_store/reports_publications/trl_reports/cat_road_user_safety/report_passion_performance_practicality_motorcyclists_motivations_and_attitudes_to_safety__motorcycle_safety_research_project.htm

Day, L., Lenne, M. G., Symmons, M., Hillard, P., Newstead, S. V., Allen, T., & McClure, R. (2013). Population based case–control study of serious nonfatal motorcycle crashes. *BMC Public Health. 13*(72), 1-13. DOI:10.1186/1471-2458-13-72

Fildes B., Logan D., Hillard P., Schofield P. The Enhanced Crash Investigation Study (ECIS). *Second European Transport Research Arena*: April 2008, Ljubljana, Slovenia. Brussels: European Commission; 2008. http://2008.traconference.eu/Programme/TRA2008PAPERS/tabid/159/Default.aspx

Haworth, N., Smith R, Brumen I, Pronk N: Case control study of motorcycle crashes. Canberra, Australia: The Federal Office of Road Safety; 1997:CR174.

Haworth, N. (2012): Powered two wheelers in a changing world- challenges and opportunities. *Accid Anal Prev*, 44:12–18.

Hillard P.J., Logan, D., Fildes, B. (2005). *The application of systems engineering techniques to the modelling of crash causation. In Driver behaviour and training: volume II*. Edited by Dorn L. Aldershot: Ashgate Publishing Ltd; 2005:407–416.

Stephan, K., Symmons, M., Hillard, P., Bohensky, M., Muir, C., & Lenne, M. G. (2008). *Characteristics of fatal motorcycle crashes involving excessive and/or inappropriate speed*. Melbourne: Monash University Accident Research Centre

Teoh, E.R. (2011). *Effectiveness of antilock braking systems in reducing motorcycle fatal crash rates.* Traffic Injury Prevention, 12:169-173.

Victorian Admitted Episodes Dataset (VAED). 1995-2012.