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# Safe system approach to reducing serious injury risk in motorcyclist collisions with fixed hazards

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ABSTRACT

Collisions with fixed objects in the roadway environment account for a substantial proportion of motorcyclist fatalities. Many studies have identified individual roadway environment and/or motorcyclist characteristics that are associated with the severity of the injury outcome, including the presence of roadside barriers, helmet use, alcohol use and speeding. However, no studies have reported the cumulative benefit of such characteristics on motorcycling safety. The safe system approach recognises that the system must work as a whole to reduce the net injury risk to road users to an acceptable level, including the four system cornerstone areas of roadways, speeds, vehicles and people. The aim of the present paper is to consider these cornerstone areas concomitantly, and quantitatively assess the serious injury risk of motorcyclists in fixed object collisions using this holistic approach. A total of 1006 Australian and 15,727 (weighted) United States motorcyclist-fixed object collisions were collected retrospectively, and the serious injury risks associated with roadside barriers, helmet use, alcohol use and speeding were assessed both individually and concomitantly. The results indicate that if safety efforts are made in each of the safe system cornerstone areas, the combined effect is to substantially reduce the serious injury risk of fixed hazards to motorcyclists. The holistic approach is shown to reduce the serious injury risk considerably more than each of the safety efforts considered individually. These results promote the use of a safe system approach to motorcycling safety.



## 1. Introduction

Single-vehicle motorcyclist collisions with fixed objects in the roadway environment account for a substantial proportion of serious motorcyclist trauma. In Australia, such collisions account for 39% of motorcyclist fatalities, and trees, utility poles, posts and roadside barriers are the fixed hazards most frequently struck (77%; Bambach et al., 2012). In the United States, fixed object collisions account for 23% of the nearly 5000 motorcyclist fatalities that occur annually (NHTSA, 2013), and trees, utility poles, posts and roadside barriers are the fixed hazards most frequently struck (59%; Bambach et al., 2011). Other authors have also highlighted the substantial injury risk of fixed objects to motorcyclists (Quddus et al., 2002; Savolainen and Mannering, 2007; Shankar and Mannering, 1996).

Previous studies of injury risk to motorcyclists have typically identified individual roadway environment and/or motorcyclist characteristics, and analysed their influence on injury risk. Typically these have involved either unadjusted risk values (fatality or injury rates), or risk values adjusted for potential confounding using statistical methods such as logistic regression to calculate odds ratios. Whether adjusting for confounding or otherwise, such techniques assess the individual association of a variable with the outcome considered. For example, several studies have identified roadside barriers as providing reduced risk of serious injury or fatality to motorcyclists, compared with colliding with the hazard they are protecting such as trees, utility poles and posts (Bambach et al., 2011, 2013; Daniello and Gabler, 2011). Several studies have identified important behaviour-related risk factors that have been shown to influence the outcome of motorcycle crashes such as helmet use and alcohol use, and were therefore considered in the present study. For example, the reduction of injury risk provided by wearing protective equipment such as motorcycle helmets (Lin and Kraus, 2009; de Rome et al., 2011), and the risk of riding under the influence of alcohol (Quddus et al., 2002; Savolainen and Mannering, 2007; Shankar and Mannering, 1996).

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The safe system approach to road safety has recently been adopted in Australia (ATC, 2011) and is based upon the principle that the four cornerstone areas of roadways, speeds, vehicles and people, when combined, provide a holistic approach to road safety. Thus while each area influences injury risk individually, the system must work as a whole to reduce the net injury risk to road users to an acceptable level. However, few studies have quantitatively assessed the combined effects of the safe system cornerstones on injury risk for motorcyclists. The aim of the present paper is to quantitatively analyse these combined effects, and to compare the holistic safe system approach with the approach of considering each effect individually. Motorcyclists in single-vehicle collisions with fixed roadside objects are examined, since such collisions account for a substantial proportion of motorcyclist trauma internationally.

## 2. Methods

### 2.1. Data collections

Crash data from both Australia and the United States were examined in the present study. These data were collected previously for assessing the serious injury risk (Bambach et al., 2013– Australian data) and the fatality risk (Bambach et al., 2011– United States data) of roadside barriers to motorcyclists, compared with other types of fixed hazards. In both studies logistic regression models were developed to assess the association of various crash characteristics with the outcome, by calculating odds ratios for each variable individually. However, the combined effect of the variables on injury risk was not assessed. The Australian and United States datasets included different types of fixed roadside hazards, thus for the present study only data for the following types of fixed objects were examined; roadside barriers (concrete barriers and steel guardrail/W-beam barriers), trees, utility poles, and posts. These objects account for the majority of motorcyclist fatalities resulting from fixed object collisions. Otherwise the datasets were exactly as described in Bambach et al. (2011, 2013); the reader is referred to these articles for the full details, however summaries of each dataset and inclusion criteria are provided herein.

The United States study (Bambach et al., 2011) used the United States National Automotive Sampling System (NASS) General Estimates System (GES), which obtains its data from 400 police jurisdictions in 60 areas that reflect the geography, roadway mileage, population, and traffic density in the US. Around 50,000 police accident reports (PARs) are sampled each year, and crashes include those that result in fatality, injury or property damage. The GES is a probability sample, and in order to calculate national crash estimates a weighting value is provided for each PAR. The weighting values were used for all analyses in the present study. The GES data were queried for the years 2000–2009 (inclusive) according to the following inclusions: the PAR involved a motorcyclist in a single-vehicle crash and the most harmful event was coded as a collision with a fixed object. Only 3.1% of such collisions were identified as having an outcome of non-injury. One would expect a large number of non-injury collisions to have occurred (e.g. the motorcycle contacts a barrier and incurs only minor damage, then simply drives away), however such crashes are rarely reported to police and may suffer from sample bias. Accordingly, non-injury collisions were excluded from the data.

The Australian study (Bambach et al., 2013) used linked road crash and hospitalisation data from the most populous Australian state of New South Wales (NSW). The crash data were a census of all police-reported crashes that occurred on public roadways in NSW, which resulted in fatality, injury or property damage. The hospitalisation data were a census of all inpatient admissions from all public, private, private day procedure and public psychiatric hospitals in NSW. The data were linked using probabilistic techniques. Linked data were extracted for the years 2001–2009 (inclusive) according to the following inclusions: the crash involved a motorcyclist in a single-vehicle crash and the impact type was identified as a collision with a fixed object. Similar to the United States GES study, very few non-injury collisions were identified and were thus excluded from the data.

### 2.2. Data analysis

Data variables associated with each of the safe system cornerstones were considered: the presence of a roadside barrier in front of the hazard (safe roadways); the motorcyclist was wearing a helmet (safe vehicles and protective devices); the crash was speed-related (safe speeds); and the crash was alcohol-related (safe people). In both the Australian and United States data the *speed-related* variable indicates that speed was a contributing factor to the cause of the crash (not necessarily speed in excess of the speed limit), and the *alcohol-related* variable indicates that alcohol use was reported (not necessarily alcohol use in excess of the blood alcohol limit). All variables were treated as dichotomous (yes/no), where *no barrier* indicates that one of the fixed hazards of trees/posts/poles were present and a roadside barrier was not.

Two different levels of injury severity outcome were considered for the Australian and United States studies; the motorcyclist was killed or hospitalised (KH), and the motorcyclist was killed or seriously injured (KSI). In the United States GES, data variables are provided indicating whether the individual went to hospital and the injury severity sustained. The injury severity is coded to the KABCO scale; killed, incapacitating injury, non-incapacitating injury, possible injury and no injury. KH indicates the individual went to hospital and/or the injury severity was killed, while KSI indicates the injury severity was either killed or incapacitating injury. In the Australian linked police-hospital dataset, injury severity was determined using the International Classification Injury Severity Score (ICISS) methodology (Davie et al., 2008), where all International Classification of Diseases, 10th Revision, Australian Modification (ICD-10-AM) coded injuries were associated with a survival rate (termed a survival risk ratio). Injuries with a survival rate of 96.5% (i.e. a mortality rate of 3.5%) were considered as *serious injuries*, indicating injuries that constitute a threat-to-life and corresponding to the measured mean survival rate of an Abbreviated Injury Scale (AIS) 3 serious injury (AAAM, 2005). KH indicates the individual went to hospital (had a linked hospital record) and/or was killed, while KSI indicates the individual went to hospital and sustained at least one ICD-10-AM injury with mortality greater than 3.5% and/or was killed. Rates of KH and KSI were calculated for both the Australian and United States data as the number of individuals that were identified as KH or KSI, divided by the total number of individuals.

The United States GES does not provide information on individual injuries sustained, however in the Australian linked police-hospital dataset all injury diagnoses were available (for those individuals that went to hospital). For these data, additional serious injury rates were calculated for each of the main body regions of head, torso (thorax, abdomen and pelvis), spine (vertebral column and spinal cord) and extremities (upper and lower). The rates were expressed as the total number of serious injuries sustained (injuries with mortality greater than 3.5%), normalised to 100 collisions (Eq. (1)).

$$\text{SI rate} = \frac{\text{total number of serious injuries} \times 100}{\text{total number of collisions}} \tag{1}$$

For the four variables considered (barrier, helmet use, speed-related and alcohol-related), each was considered individually by disaggregating the data into two groups (yes/no) and calculating the KH, KSI and SI rates. The four variables were then considered concomitantly, by identifying only individuals that met the criteria for the following two groups: no barrier, no helmet, speed and alcohol-related (NB, NH, S, A); barrier present, helmet used, not speed nor alcohol-related (B, H, NS, NA). The latter group considers motorcyclists operating under a safe system approach, and KH, KSI and SI rates were calculated for both groups.

## 3. Results

There were a weighted total of 15,727 ($n_{\text{unweighted}} = 444$) motorcyclists in the United States GES and 1006 motorcyclists in the Australian linked police-hospital data, identified as being involved in a single-vehicle collision with a roadside barrier, tree, post or pole. The case counts, KH, KSI rates and 95% confidence intervals are tabulated in Table 1 and plotted in Fig. 1. The overall KH rates for the collisions were relatively high (68% and 82% for the Australian and United States data, respectively). The rates of KH considering the variables individually (Fig. 1a–d) generally decreased when a barrier was present, when the motorcyclist was helmeted, when speed was not involved or when alcohol was not involved (except for helmet use in Australia). The overall KSI rates were lower than the KH rates (45% and 51% for the Australian and United States data, respectively), and the same trends were observed when the variables were considered individually. The KH and KSI rates were similar for both countries, however those for Australia were lower than those for the United States.

When the four variables were considered concomitantly (Fig. 1e), substantial differences were apparent between the two groups considered, and the differences in rates were substantially more pronounced than those when each of the variables were considered individually. The KH rate reduced from 81% to 63% in the United States data and from 81% to 53% in the Australian data with the safe system approach of a barrier, helmet use and without speed and alcohol, compared with the converse. Correspondingly, the KSI rate reduced from 67% to 40% in the United States data and from 69% to 23% in the Australian data with the safe system approach.

The SI rates for the Australian data are tabulated in Table 2 and plotted in Fig. 2, and the overall SI rate was 121 serious injuries per 100 collisions. As with the KH and KSI data, when considering the variables individually (Fig. 2a–d) the rates generally decreased when a barrier was present, when the motorcyclist was helmeted, when speed was not involved or when alcohol was not involved (except for the torso for helmet use and alcohol use, the spine for helmet use and the extremities for speeding-related). The differences in rates were substantially more pronounced when the variables were considered concomitantly (Fig. 2e). The SI rate reduced from 188 to 58 serious injuries per 100 collisions with the safe system approach of a barrier, helmet use and without speed and alcohol, compared with the converse.

## 4. Discussion

The results indicate that the presence of a roadside barrier, wearing of a helmet, not riding with excessive speed and not riding under the influence of alcohol each typically provided modest safety benefits to motorcyclists in fixed object collisions individually, as indicated by reductions in KH and KSI rates of up to 1.14 and 1.43 times, respectively. However, the greatest safety benefits were achieved when all measures occurred concomitantly, i.e. the safe system approach. In these cases, reductions in KH and KSI rates of up to 1.53 and 2.93 times, respectively, were evident. The safety benefits were more pronounced when the more serious injury outcome of KSI was considered. The greatest benefits of the

**Table 1**
Hospitalised or killed (KH) and seriously injured or killed (KSI) rates for motorcyclists in fixed-object collisions in Australia and the United States.

| | United States GES | | | | | United States GES | | | | | Australian linked police-hospital | | | | | Australian linked police-hospital | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total persons | KH persons | KH rate | $CL_L$ | $CL_U$ | Total persons | KSI persons | KSI rate | $CL_L$ | $CL_U$ | Total persons | KH persons | KH rate | $CL_L$ | $CL_U$ | Total persons | KSI persons | KSI rate | $CL_L$ | $CL_U$ |
| Tree/post/pole | 7652 | 6605 | 0.86 | 0.85 | 0.87 | 7652 | 4157 | 0.54 | 0.52 | 0.57 | 673 | 470 | 0.70 | 0.64 | 0.76 | 673 | 339 | 0.50 | 0.40 | 0.61 |
| Barrier | 8076 | 6281 | 0.78 | 0.76 | 0.79 | 8076 | 3911 | 0.48 | 0.45 | 0.52 | 333 | 212 | 0.64 | 0.53 | 0.74 | 333 | 117 | 0.35 | 0.11 | 0.60 |
| No helmet | 6160 | 5240 | 0.85 | 0.84 | 0.86 | 6160 | 3847 | 0.62 | 0.60 | 0.65 | 136 | 88 | 0.65 | 0.49 | 0.80 | 136 | 59 | 0.43 | 0.14 | 0.73 |
| Helmet | 9566 | 7646 | 0.80 | 0.79 | 0.81 | 9566 | 4222 | 0.44 | 0.41 | 0.48 | 870 | 594 | 0.68 | 0.63 | 0.74 | 870 | 397 | 0.46 | 0.35 | 0.56 |
| Not speed-related | 7465 | 5731 | 0.77 | 0.75 | 0.78 | 7465 | 3512 | 0.47 | 0.44 | 0.51 | 305 | 189 | 0.62 | 0.51 | 0.73 | 305 | 119 | 0.39 | 0.17 | 0.61 |
| Speed-related | 8262 | 7155 | 0.87 | 0.86 | 0.88 | 8262 | 4556 | 0.55 | 0.53 | 0.58 | 701 | 493 | 0.70 | 0.65 | 0.76 | 701 | 337 | 0.48 | 0.37 | 0.59 |
| Not alcohol-related | 12,533 | 10,223 | 0.82 | 0.81 | 0.82 | 12,533 | 6367 | 0.51 | 0.48 | 0.53 | 872 | 580 | 0.67 | 0.61 | 0.72 | 872 | 375 | 0.43 | 0.31 | 0.55 |
| Alcohol-related | 3193 | 2663 | 0.83 | 0.82 | 0.85 | 3193 | 1702 | 0.53 | 0.49 | 0.58 | 134 | 102 | 0.76 | 0.65 | 0.87 | 134 | 81 | 0.60 | 0.43 | 0.78 |
| NB, NH, S, A[a] | 301 | 244 | 0.81 | 0.75 | 0.87 | 301 | 202 | 0.67 | 0.57 | 0.77 | 16 | 13 | 0.81 | 0.55 | 0.98 | 16 | 11 | 0.69 | 0.43 | 0.95 |
| B, H, NS, NA[b] | 2251 | 1409 | 0.63 | 0.59 | 0.67 | 2251 | 908 | 0.40 | 0.32 | 0.48 | 64 | 34 | 0.53 | 0.22 | 0.85 | 64 | 15 | 0.23 | 0.09 | 0.55 |

$CL_L$ = lower 95% confidence limit, $CL_U$ = upper 95% confidence limit.
[a] No barrier, no helmet, speeding-related and alcohol-related (NB, NH, S, A).
[b] Barrier present, helmet used, not speeding-related and not alcohol-related (B, H, NS, NA).

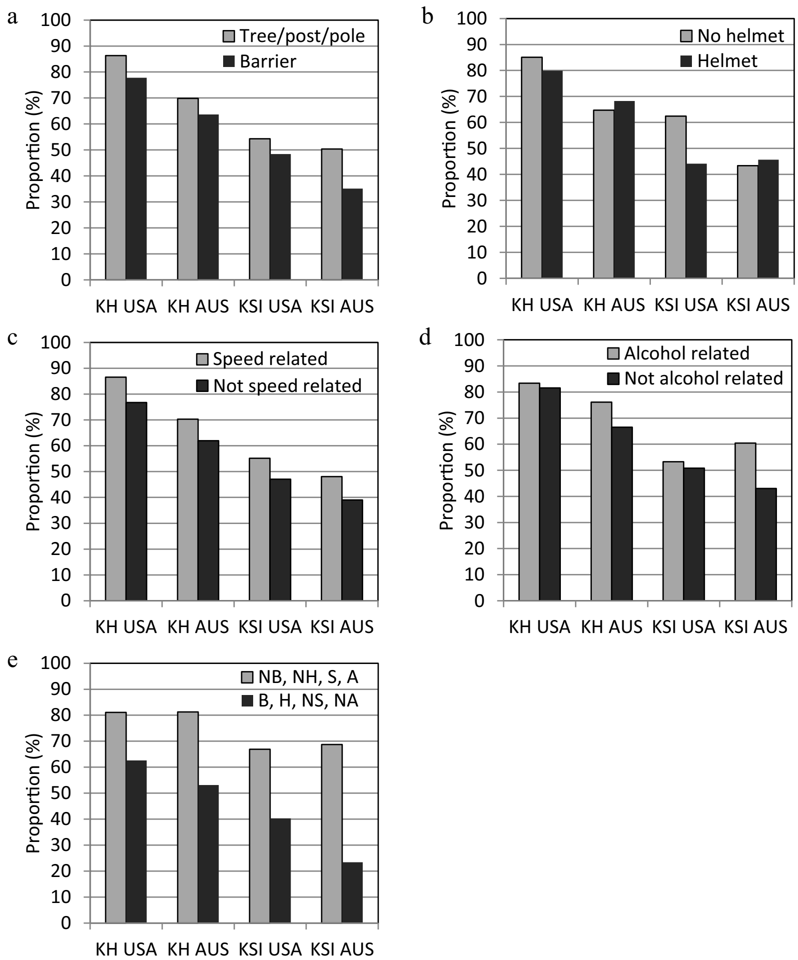


**Fig. 1.** Hospitalised or killed (KH) and seriously injured or killed (KSI) rates for motorcyclists in fixed-object collisions in Australia (AUS) and the United States (US), considering (a) object struck, (b) helmet use, (c) speeding and (d) alcohol use, individually, or (e) considering all variables concomitantly (safe system approach). (NB, NH, S, A = no barrier, no helmet, speeding-related and alcohol-related). (B, H, NS, NA = barrier present, helmet used, not speeding-related and not alcohol-related).

safe system approach were demonstrated by the Australian data when considering total serious injuries sustained, where the rate of serious injuries per 100 collisions reduced by 3.24 times.

The KSI rates may be generally interpreted as crude (unadjusted) injury risk values. Accordingly, the results indicate that the risk of a motorcyclist being seriously injured or killed as a result of a collision with a fixed object is minimised to 23% or 40% (Australia and the United States, respectively) when a safe system approach is adopted. Similarly, the risk of sustaining individual serious injuries to the various body regions is minimised, particularly those to the head and spine.

Other studies have demonstrated the individual safety benefits to motorcyclists of roadside barriers, wearing a helmet, not riding with excessive speed and not riding under the influence of alcohol. Bambach et al. (2011) and Daniello and Gabler (2011) both demonstrated that the fatality risk of trees and posts/poles to motorcyclists were significantly greater than that for barriers, and Bambach et al. (2013) found a similar result when considering the

**Table 2**
Serious injuries (ICD-10-AM injury with mortality ≥3.5%) sustained per 100 collisions for motorcyclists in fixed-object collisions in Australia.

| | Total persons | Head SI per 100 collisions | Torso SI per 100 collisions | Spine SI per 100 collisions | Extremities SI per 100 collisions | Total SI per 100 collisions |
|---|---|---|---|---|---|---|
| Tree/post/pole | 673 | 31 | 63 | 15 | 31 | 141 |
| Barrier | 333 | 10 | 40 | 7 | 25 | 82 |
| No helmet | 136 | 41 | 32 | 6 | 29 | 108 |
| Helmet | 870 | 21 | 60 | 13 | 29 | 123 |
| Not speed-related | 305 | 24 | 37 | 10 | 30 | 101 |
| Speed-related | 701 | 24 | 64 | 14 | 29 | 130 |
| Not alcohol-related | 872 | 19 | 58 | 12 | 26 | 116 |
| Alcohol-related | 134 | 54 | 43 | 15 | 47 | 158 |
| NB, NH, S, A[a] | 16 | 94 | 56 | 13 | 25 | 188 |
| B, H, NS, NA[b] | 64 | 9 | 28 | 5 | 16 | 58 |

SI = serious injuries (ICD-10-AM injury with mortality ≥3.5%).

[a] No barrier, no helmet, speeding-related and alcohol-related (NB, NH, S, A).

[b] Barrier present, helmet used, not speeding-related and not alcohol-related (B, H, NS, NA).

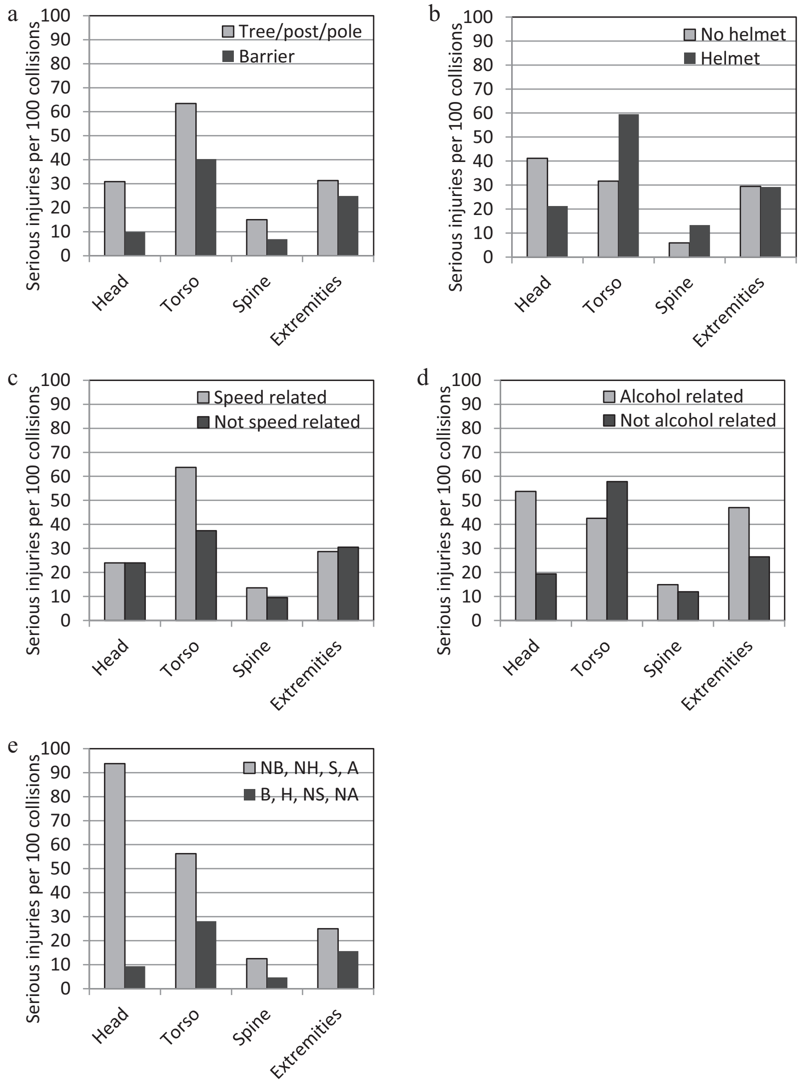


**Fig. 2.** Serious injuries (ICD-10-AM injury with mortality ≥3.5%) sustained per 100 collisions for motorcyclists in fixed-object collisions in Australia, considering (a) object struck, (b) helmet use, (c) speeding and (d) alcohol use, individually, or (e) considering all variables concomitantly (safe system approach). (NB, NH, S, A = no barrier, no helmet, speeding-related and alcohol-related). (B, H, NS, NA = barrier present, helmet used, not speeding-related and not alcohol-related).

serious injury risk. The safety benefits of helmets to motorcyclists have been described extensively in the literature (see for example the literature review by Lin and Kraus, 2009). Speed-related crashes are well known to be related to more severe motorcyclist injury outcomes (Savolainen and Mannering, 2007; Shankar and Mannering, 1996), likely a result of the fact that such crashes typically involve greater crash kinetic energy. Similarly, impairment due to alcohol use is well established as being associated with increased injury severity risk amongst motorcyclists (Savolainen and Mannering, 2007; Shankar and Mannering, 1996).

The overall KH and KSI rates for the single-vehicle motorcyclist collisions with fixed objects were relatively high (68–82% and 45–51%, respectively), which results from the fact that motorcyclists are unprotected and also reflects the inclusion criterion for the data collections. Considering the former, motorcyclists do not have a vehicle structure to protect them in the collision with the fixed object and consequently are highly susceptible to injury. In a recent study of passenger vehicle casualty collisions with barriers, trees and utility poles in Australia (Jurewicz et al., 2012), the overall KH rate was 51% ($n$ = 3062). Compared with the present Australian overall rate of 68% for motorcyclists, fixed objects are clearly more hazardous to motorcyclists than passenger vehicle occupants. Considering the latter, both the Australian and United States data excluded non-injury collisions, since the case counts were small as a result of such collisions rarely being reported to police. If a reliable technique of quantifying non-injury collisions could be established and these collisions included in the data, the KH and KSI rates would likely be substantially reduced.

While the KH rates between Australia and the United States were similar, the overall rate for Australia of 68% was lower than that for the United States of 82%. While the roadway environments are generally relatively similar in Australia and the United States, it is likely that the motorcyclists involved in the collisions considered in the present study had different characteristics and/or the fixed objects/roadway environments were different between the two countries. For example, the helmet wearing rates (88% in the Australian data and 61% in the United States data), the proportion located on highways (19% in the Australian data and 5% in the United States data), and many possible differences in roadway design (such as the design and placement of roadside barriers, pavement design and roadway friction, shoulder and clear zone design, etc.) and rider characteristics (motorcycle types, riding styles, riding speeds, etc.). The KSI rates also differed between the two countries, which might be related to the above mentioned

**Table 3**
Univariate logistic regression results for motorcyclists in fixed-object collisions in Australia and the United States, for the association between the safe system variable and an outcome of seriously injured or killed (KSI).

| Safe system variable values | United States GES | | | | Australian linked police-hospital | | | |
|---|---|---|---|---|---|---|---|---|
| | Odds ratio | $CL_L$ | $CL_U$ | *p* value | Odds ratio | $CL_L$ | $CL_U$ | *p* value |
| No barrier, no helmet, speeding-related, alcohol-related | 1 | | | | 1 | | | |
| Barrier (no helmet, speeding-related, alcohol-related) | 0.33 | 0.24 | 0.47 | <.001 | 0.23 | 0.02 | 3.13 | 0.27 |
| Helmet (no barrier, speeding-related, alcohol-related) | 0.50 | 0.37 | 0.67 | <.001 | 0.97 | 0.30 | 3.14 | 0.96 |
| Not speeding-related (no barrier, no helmet, alcohol-related) | 0.89 | 0.66 | 1.19 | 0.43 | 0.37 | 0.09 | 1.47 | 0.16 |
| Not alcohol-related (no barrier, no helmet, speeding-related) | 1.20 | 0.92 | 1.56 | 0.19 | 0.41 | 0.12 | 1.41 | 0.16 |
| Two or three of; barrier, helmet, not speeding-related, not alcohol-related | 0.50 | 0.39 | 0.64 | <.001 | 0.37 | 0.13 | 1.06 | 0.06 |
| Barrier, helmet, not speeding-related, not alcohol-related | 0.33 | 0.26 | 0.43 | <.001 | 0.14 | 0.04 | 0.46 | 0.01 |

$CL_L$ = lower 95% confidence limit, $CL_U$ = upper 95% confidence limit.

differences in motorcyclist and/or roadway characteristics and/or the different methods used for identifying a seriously injured motorcyclist. As a result of these differences between countries, the safe system approach (considering the four variables concomitantly) demonstrated different magnitudes of benefit considering both outcomes of KH and KSI, however the substantial benefit was clear in both countries.

Some KH and KSI rates did not correspond with the general trends observed for the safety potential of the individual variables, for example the rates for helmeted motorcyclists in the Australian data were more than those for unhelmeted motorcyclists. When disaggregated by injured body region in Fig. 2b, the serious head injury rate for helmeted motorcyclists was around one half of that for unhelmeted motorcyclists, which confirms the safety benefit of helmets in reducing head injuries. However, the rate of torso injuries was around two times higher for helmeted motorcyclists, which resulted in the KH and KSI rates being greater for helmeted motorcyclists. This result should not be interpreted as helmet wearing being associated with the incidence of torso injuries, rather, there are variables that are confounding the data. Since confounding was not controlled for in the present study, there may be instances where the results have been affected by other variables, for example there may be differences in rider characteristics between helmeted and unhelmeted riders that result in different riding habits and skills that result in different injury outcomes (Shankar and Mannering, 1996).

As noted in the introduction, statistical methods such as logistic regression assess the individual association of a variable with the outcome considered, thus are not well suited to the aim of the present study of assessing the combined benefits of the safe system approach (i.e. assessing all variables concomitantly). Logistic regression treats each variable one at a time, and assesses its association with the outcome while assuming all other variables remain the same (see Table 2 in Bambach et al., 2011 and Table 2 in Bambach et al., 2013), for logistic regression analyses of the data used in the present study). However, a logistic regression analysis may be setup using a dummy variable as a 'safe system' variable, which conflates the four variables considered in the present study into one variable. An example is shown in Table 3, where univariate logistic regression is performed for the outcome of KSI. Rather than using all 16 values (for the four dichotomous variables), cases with two or three values in accordance with a safe system were grouped together. While relatively difficult to interpret for these cases due to the grouping and the choice of referent, the benefit of the safe system approach (helmet, barrier, not speed-related and not alcohol-related) compared with not (no helmet, no barrier, speed-related and alcohol-related) is clear in the table. The odds of KSI for a safe system were several times lower in both the Australian and United States data, in accordance with the results discussed previously. Future studies could consider improved logistic regression techniques or other advanced statistical methods to further consolidate the safe system benefits identified in the present study.

## 5. Limitations

There are several limitations of the study that should be noted. The United States GES data is a probability sample, not a census. There may be errors involved in the weighting values used, however, comparison with the unweighted results indicated the results were not significantly different. Both the Australian and United States data were derived from police reported crashes, however, not all crashes that occur are reported to police. There may be discrepancies between the manner in which different police jurisdictions record different particulars of a crash, and there may be errors involved in the coding processes. The injury designations in the police reports are subjective and based on the interpretations of police officers. For the Australian data, the probabilistic linkage method is not without possible linkage errors, however, false positives and false negatives were estimated to be 0.4% and 0.5%, respectively. The 95% confidence intervals for the Australian data were relatively large, due to the relatively small case counts. Confounding was not controlled for in the present study, which might have resulted in variable results being affected by other variables that were unaccounted for.

One pillar of the safe system approach is the vehicle, however vehicle-related factors could not be assessed in the present study, since the data collections used did not provide detail on the presence or use of motorcycle safety devices such as ABS braking or airbags. Further, information on other behavioural factors such as rider distraction and fatigue could not be adequately identified with the present data collections, and were therefore not assessed in the present study. In both the GES and the Australian police-reported data collections the variables indicating that the crash was speed-related or alcohol-related was inferred by the data collection coders from the text narrative on the police report. If a speeding infringement was issued then the speed-related variable was 'yes', otherwise this was inferred from various text descriptions at the discretion of the coders. Similarly, the variable indicating that the crash was alcohol-related was 'yes' if the driver had an alcohol test and it indicated a non-zero value, otherwise if an alcohol test was not performed this was inferred from the text narrative at the discretion of the coders. Different coders may have interpreted text narratives in different ways, and differences may have occurred between countries, and these may have affected the results in the present study. The different types of roadside barriers used on public roadways would likely have varied between Australia and the United States, and indeed would likely vary between states and geographical regions within these countries. The barrier mix would likely affect the frequency of barrier crashes in each region due to exposure, which may have influenced the results in the present study.

## 6. Conclusions

Fixed hazards in the roadway environment present a substantial risk to motorcyclists, and result in many serious injuries and fatalities. Several safety initiatives have been identified in the literature and shown to be individually associated with reduced injury severity outcomes for motorcyclists, including protecting hazards with roadside barriers, helmet use, reduced speeds and not consuming alcohol. The present study has confirmed the individual safety benefits of such approaches in Australia and the United States, and has additionally quantified the substantial safety benefits of such approaches when applied concomitantly, thereby quantifying the benefits of a safe system approach. The holistic system approach has been shown to reduce the risk of serious injury to motorcyclists in fixed object collisions to as little as 23%. The quantifications provided may be useful to motorcycling groups, road authorities and road safety advocates in promoting the use of a safe system approach to motorcycling safety.

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