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# Sleep-related vehicle crashes on low speed roads

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## Highlights

- 10y of police reported sleep-related (SR) crashes were analysed: high vs low speed; low speed SR vs not-SR.
- Young (16-24y) males are overrepresented in SR crashes.
- Low speed SR crashes have similar characteristics to high speed SR crashes.
- SR crashes on low speed roads have more severe outcomes than not-SR crashes.
- Driver education should be broadened, including implications for driver sleepiness on low speed roads.

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## Abstract

**Background:** Very little is known about the characteristics of sleep related (SR) crashes occurring on low speed roads compared with current understanding of the role of sleep in crashes occurring on high speed roads e.g. motorways. To address this gap, analyses were undertaken to identify the differences and similarities between (1) SR crashes occurring on roads with low ( $\leq 60$ km/h) and high ( $\geq 100$ km/h) speed limits, and (2) SR crashes and not-SR crashes occurring on roads with low speed limits.

**Method:** Police reports of all crashes occurring on low and high speed roads over a ten year period between 2000 and 2009 were examined for Queensland, Australia. Attending police officers identified all crash attributes, including 'fatigue/fell asleep', which indicates that the police believe the crash to have a causal factor relating to falling asleep, sleepiness due to sleep loss, time of day, or fatigue. Driver or rider involvement in crashes was classified as SR or not-SR. All crash-associated variables were compared using Chi-square tests (Cramer's V = effect size). A series of logistic regression were performed, with driver and crash characteristics as predictors of crash category. A conservative alpha level of .001 determined statistical significance.

**Results:** There were 440,855 drivers or riders involved in a crash during this time; 6,923 (1.6%) were attributed as SR. SR crashes on low speed roads have similar characteristics to those on high speed roads with young (16-24y) males consistently over represented. SR crashes on low speed roads are noticeably different to not-SR crashes in the same speed zone in that male and young novice drivers are over represented and outcomes are more severe. Of all the SR crashes identified, 41% occurred on low speed roads.

**Conclusion:** SR crashes are not confined to high speed roads. Low speed SR crashes warrant specific investigation because they occur in densely populated areas, exposing a greater number of people to risk and have more severe outcomes than not-SR crashes on the same low speed roads.

1 **Key words:** driver sleepiness, driver drowsiness, driver fatigue, road crash, police data

## 2 **1 Introduction**

3 Sleep-related (SR) crashes are a road safety problem the world over (Åkerstedt, 2000). Drivers who  
4 are sleepy are at an almost six fold increase in the odds of having an injury involved crash (Herman  
5 *et al.* 2014). It has been demonstrated that SR crashes are prevalent on high speed motorways (e.g.  
6 Connor *et al.* 2002, Philip *et al.* 2014). Reflecting this, the majority of driver sleepiness research has  
7 been targeted at understanding and mitigating SR incidents during motorway driving (e.g. Philip *et*  
8 *al.* 2005, Filtness *et al.* 2012, Hallvig *et al.* 2013). However, self-reported experience by drivers of SR  
9 driving incidents suggest that approximately 25% of SR incidents occur on roads with a speed limit of  
10  $\leq 50\text{km/h}$  (31mph), with a further 30% occurring on roads with speed limits between 50 and 80km/h  
11 (31-50mph) (Armstrong *et al.* 2013). To date, little attempt has been made to specifically investigate  
12 these low speed SR crashes therefore it is unknown how these differ from either not-SR crashes of a  
13 similar speed or high speed SR crashes.

14 Driver sleepiness is common, with 9% of French drivers ( $n = 35,000$ ) reporting being so sleepy that  
15 they have to stop driving at least once per month (Philip *et al.* 2010), and 8% of Norwegian drivers  
16 reporting having fallen asleep while driving in the past month (Sagberg 1999). Experimental  
17 investigations using driving simulators and on-road driving protocols have demonstrated that sleepy  
18 drivers have impaired driving performance in terms of increased number of out of lane events (e.g.  
19 Horne and Reyner 1996), variability in lane positioning (e.g. Anund *et al.* 2008; Forsman *et al.*, 2013)  
20 and variability in speed control (e.g. Matthews *et al.* 2012). These investigations (and many others)  
21 have provided important insight into driver sleepiness, but in each case the influence of sleepiness  
22 on driving performance was examined in high speed zone motorways or high speed zone scenarios  
23 meaning that it is unknown whether findings can be inferred to low speed driving conditions or not.  
24 Furthermore, education and awareness campaigns have sought to highlight the dangers of  
25 sleepiness associated with long distance driving, with many strategies targeted towards motorway

1 driving e.g. road signs advising drivers to take a break, while driver sleepiness in low speed zones is  
2 largely overlooked.

3 The focus of research attention towards high speed zones is arguably warranted as analyses of crash  
4 data demonstrate SR crashes to be most common in high speed zones, with driving on a highway a  
5 leading predictor of SR crash (Philip *et al.* 2014). However, using such a focused approach to both  
6 education and awareness campaigns and targeted maximum driving hours requirements for heavy  
7 vehicles, could result in drivers believing that driver sleepiness is a problem isolated to high speed  
8 motorways. Therefore, it is possible that drivers may ignore or overlook the danger during city  
9 driving. Similarly, targeted interventions may be missing some important aspects related to driver  
10 sleepiness on low speed roads.

11 Understanding whether low speed SR crashes differ from high speed SR crashes is necessary in  
12 determining whether those road safety countermeasures applied in high speed environments (e.g.  
13 driver sleepiness advise warning signs) may also be relevant for low speed environments. This is  
14 particularly important as many drivers report having experienced a SR incident on a low speed road  
15 and any SR incidents (regardless of speed zone) are most common when commuting to and from  
16 work (Armstrong *et al.* 2013). Highly dynamic urban driving requires quick responses and quick  
17 decision making in a complex and often shared road environment. Both reaction time (Belenky *et al.*  
18 2003) and flexibility of decision making in cognitive tasks (Harrison and Horne 2000) are known to be  
19 impaired by sleepiness, suggesting that sleepy drivers may have impaired responses to safety critical  
20 events. Low speed roads are predominantly located in highly populated areas exposing a greater  
21 number of people to risk from a sleepy driver than the equivalent driver on a high speed road.  
22 However, there is a dearth of literature exploring sleep related impairment in an urban driving  
23 context. A first step in understanding the impact of sleepiness on low speed driving performance is  
24 to examine its consequence through analysis of crash data from low speed zones.

1 The objective of the current work was to quantify the characteristics of SR crashes occurring on low  
2 ( $\leq 60$ km/h; approximately  $\leq 37$ mph) speed roads in comparison to both high ( $\geq 100$ km/h;  
3 approximately  $\geq 62$ mph) speed road SR crashes and to not-SR crashes on the same low speed areas.  
4 Both vehicle operator and crash characteristics from police crash report data were considered.  
5 Statistical analysis sought to identify similarities between high and low speed sleep crashes and  
6 differences between SR and not-SR crashes on low speed roads.

## 7 **2 Methods**

### 8 **2.1 Crash data**

9 Queensland (Australia) police reports for crashes occurring on low ( $\leq 60$ km/h) and high ( $\geq 100$  km/h)  
10 speed roads between 1<sup>st</sup> January 2000 and 31<sup>st</sup> December 2009 were examined. Ten years of crash  
11 data provided sufficient scope for identifying general trends and permitted meaningful comparisons  
12 between SR and not-SR crashes. Police crash reports detail those crashes which occur on a public  
13 road, and where: a person was killed or injured, a vehicle towed, or greater than \$2500 of damage to  
14 property other than vehicles was incurred. Crashes resulting from medical conditions and deliberate  
15 acts were excluded. Police crash reports detail vehicle operator characteristics and crash  
16 characteristics as well as crash causal factors (multiple causal factors may be identified for each  
17 crash); these are all identified by the reporting Queensland Police Services (QPS) officer. Serious  
18 crashes (fatal or serious injury) are attended by the Forensic Crash Investigation unit, where specially  
19 trained officers will seek detailed information about the circumstances during and prior to the crash  
20 which can include the extent of prior sleep. All non-serious crashes are attended by regular  
21 enforcement officers.

22 All crash reports where the contributory factor "fatigue/fell asleep" was noted were classified as SR.  
23 In assigning this contributory factor the crash database does not distinguish between crashes due to

1 falling asleep while driving, sleepiness due to sleep loss, time of day, duration of driving or fatigue  
2 etc., although these may have been considered by the attending officer.

3 In order to include driver characteristics as variables of interest the main unit of analysis was the  
4 drivers or riders involved in crashes during the period, rather than crashes per se. Crash reports  
5 were grouped into four crash categories:

- 6 1. Sleep-related on  $\geq 100$  km/h speed roads (SR-H)
- 7 2. Not sleep-related on  $\geq 100$  km/h speed roads (Not SR-H)
- 8 3. Sleep-related on  $\leq 60$  km/h speed roads (SR-L)
- 9 4. Not sleep-related on  $\leq 60$  km/h speed roads (Not SR-L)

10 This work extends a previous investigations which used sub-sets of this sleep-related crash data  
11 (Armstrong *et al.* 2008, Filtner *et al.* in press). Within Queensland, local government authorities  
12 retrospectively apply a proxy definition to police crash data in order to identify sleep-related crashes  
13 which were potentially missed by the police. This is a desk based exercise applied externally from  
14 police investigations and is not considered in the current work. All presented analysis is for crash  
15 data as recorded by the police.

## 16 **2.2 Statistical Analysis**

17 For each variable, comparison was made between category 1 and 3 and category 3 and 4.

18 Categorical data were analysed using Chi-square ( $\chi^2$ ) tests with Cramer's V ( $\phi_c$ ) as an estimate of  
19 effect size. Post-hoc analyses were undertaken within each variable using the adjusted standardised  
20 residual statistic ( $\hat{e}$ ).

21 A multivariate analysis consisting of a series of logistic regressions were performed, with  
22 driver/crash characteristics as predictors of crash category. The crash characteristics are defined by  
23 the Queensland Department of Transport and Main Roads (2014). In the interests of parsimony, only  
24 statistically significant predictors at the bivariate level were included in the model. A significance

1 level ( $\alpha$ ) of .001 was used to control for the effects of large sample size. Accordingly, standard  
 2 residuals outside  $\pm 3.29$  were considered statistically significant. All statistical analyses were  
 3 conducted using IBM SPSS 19.0 statistical software.

### 4 **3 Results**

5 Overall, there were 440,855 vehicle operators (drivers and riders) involved in crashes on Queensland  
 6 roads with speed zones of interest during the time period. Of these crashes 6,923 (1.6%) were  
 7 considered by the police to be sleep-related, with 41.1% of these occurring in low speed zones (see  
 8 Table 1 for breakdown by speed zone).

9 Table 1: Number and proportion of sleep-related crashes for  $\leq 60\text{km/h}$  speed zones and  $\geq 100\text{km/h}$   
 10 speed zones

	$\leq 60\text{km/h}$ speed roads	$\geq 100\text{km/h}$ speed roads
All drivers or riders	306,300	65,205
Fatigue/fell asleep (%)	2,408 (0.7%)	3,449 (5.3%)

#### 11 **3.1 Vehicle operator characteristics**

##### 12 **3.1.1 Low speed sleep-related crashes vs high speed sleep-related crashes**

13 The proportion of crashes including each vehicle operator variable of interest is displayed in Table 2.  
 14 Compared with SR-H crashes, SR-L crashes involved a lower percentage of heavy vehicles [ $\chi^2(3) =$   
 15  $74.06, p < .001, \phi_c = .11$ ] and vehicles carrying passengers [ $\chi^2(1) = 96.77, p < .001, \phi_c = .13$ ]. There  
 16 were no statistically significant differences based on gender [ $\chi^2(1) = 3.13, p = .077, \phi_c = .02$ ]; age  
 17 group [ $\chi^2(2) = 14.86, p = .002, \phi_c = .05$ ]; licence level [ $\chi^2(3) = 2.57, p = .464, \phi_c = .02$ ] or drink driving  
 18 [ $\chi^2(1) = 0.01, p = .908, \phi_c = .0002$ ].

##### 19 **3.1.2 Low speed sleep-related crashes vs low speed not sleep-related crashes**

20 Considering all crashes on  $\leq 60\text{km/hr}$  speed roads, a higher percentage of those drivers or riders  
 21 who were involved in SR crashes were male [ $\chi^2(1) = 134.31, p < .001, \phi_c = .02$ ]; aged 16-24 years  
 22 [ $\chi^2(2) = 69.20, p < .001, \phi_c = .02$ ]; hold a provisional driver's licence or be unlicensed [ $\chi^2(3) = 69.49, p$



1 < .001,  $\phi_c = .02$ ]; and be over the prescribed alcohol limit [ $\chi^2(1) = 89.20, p < .001, \phi_c = .02$ ]. For those  
 2 drivers or riders involved in crashes on  $\leq 60$ km/hr speed roads, a lower percentage of those drivers  
 3 whose crash circumstances were attributed to be SR were motorcyclists [ $\chi^2(3) = 201.46, p < .001, \phi_c$   
 4 = .03] and a higher percentage were carrying passengers [ $\chi^2(1) = 96.70, p < .001, \phi_c = .02$ ].

5 Table 2: Characteristics of vehicle operators involved in a crash for each crash category between 1<sup>st</sup>  
 6 January 2000 and 31<sup>st</sup> December 2009

Variable	$\geq 100$ km/hr speed roads		$\leq 60$ km/hr speed roads	
	Sleep-related	Not sleep-related	Sleep-related	Not sleep-related
<i>Gender</i>	(n = 3,437)	(n = 60,533)	(n = 1,978)	(n = 286,112)
Male	76.8 %	69.4%	74.7%	61.6%
Female	23.2%	30.6%	25.3%	38.4%
<i>Age</i>	(n = 3,425)	(n = 60,105)	(n = 1,975)	(n = 282,685)
16-24	34.5%	25.9%	36.5%	28.8%
25-59	55.0%	63.6%	56.2%	60.1%
60 and over	10.5%	10.5%	7.3%	11.1%
<i>Licence Level</i>	(n = 3,215)	(n = 56,932)	(n = 1,883)	(n = 273,920)
Open	70.1%	79.6%	69.3%	77.3%
Provisional	22.2%	14.8%	22.3%	16.6%
Learner	2.6%	2.0%	3.3%	2.4%
Unlicensed	5.0%	3.6%	5.1%	3.7%
<i>Vehicle Type</i>	(n = 3,449)	(n = 61,756)	(n = 2,408)	(n = 303,892)
Car	88.0%	83.3%	95.3%	85.5%
Motorcycle	0.5%	4.4%	0.4%	4.4%
Heavy Vehicle	8.2%	9.2%	3.8%	4.1%
Other	3.3%	3.1%	0.6%	6.0%
<i>No. of occupants</i>	(n = 3,434)	(n = 61,230)	(n = 1,985)	(n = 290,975)
One	67.6%	64.8%	79.8%	68.1%
More than one	32.4%	35.2%	20.2%	31.9%
<i>Driver over alcohol limit</i>	(n = 3,449)	(n = 61,756)	(n = 2,408)	(n = 303,892)
Yes	7.7%	4.5%	7.8%	4.2%
No	92.3%	95.5%	92.2%	95.8%

## 7 3.2 Crash Characteristics

### 8 3.2.1 Low speed sleep-related crashes vs high speed sleep-related crashes

9 The proportion of each crash characteristic of interest is displayed in Table 3. Comparing SR-L and  
 10 SR-H revealed a statistically significant difference in crash severity [ $\chi^2(4) = 261.55, p < .001, \phi_c = .19$ ].  
 11 Specifically, SR-L crashes had a lower proportion than expected of serious crashes (i.e., fatal or  
 12 requiring hospitalisation). Also, SR-L crashes had a lower proportion than expected of sideswipe

1  $[\chi^2(1) = 17.07, p < .001, \phi_c = .05]$  and overturned  $[\chi^2(1) = 578.19, p < .001, \phi_c = .31]$  crashes compared  
 2 with SR-H crashes. Conversely, SR-L crashes had a greater proportion than expected of hitting an  
 3 object  $[\chi^2(1) = 138.90, p < .001, \phi_c = .15]$ , rear-end  $[\chi^2(1) = 74.39, p < .001, \phi_c = .11]$ , and angle  $[\chi^2(1) =$   
 4  $152.27, p < .001, \phi_c = .16]$  crashes occurring at dusk, dawn, or in darkness  $[\chi^2(2) = 39.81, p < .001, \phi_c =$   
 5  $.08]$ , between 10pm and 6am  $[\chi^2(3) = 40.68, p < .001, \phi_c = .08]$ , at intersections  $[\chi^2(1) = 661.10, p <$   
 6  $.001, \phi_c = .34]$ , and with traffic control  $[\chi^2(1) = 485.35, p < .001, \phi_c = .29]$ . There were no statistically  
 7 significant differences for SR crashes in the different speed zones on atmospheric conditions  $[\chi^2(3) =$   
 8  $21.01, p = .002, \phi_c = .06]$ , whether it was a head-on crash  $[\chi^2(1) = 8.12, p = .004, \phi_c = .04]$ , or day of  
 9 week  $[\chi^2(1) = 0.01, p = .927, \phi_c = .001]$ .

### 10 **3.2.2 Low speed sleep-related crashes vs low speed not sleep-related crashes**

11 Considering all crashes in low speed zones, there was a statistically significant difference in crash  
 12 severity  $[\chi^2(4) = 70.41, p < .001, \phi_c = .02]$  between SR-L and not SR-L crashes. Specifically, SR-L  
 13 crashes had a higher proportion than expected of serious crashes (i.e., fatal or hospitalisation) than  
 14 did not SR-L crashes. Also, SR-L crashes had a greater proportion than expected of hit object  $[\chi^2(1) =$   
 15  $4972.72, p < .001, \phi_c = .13]$ , head-on  $[\chi^2(1) = 193.46, p < .001, \phi_c = .03]$ , and overturned  $[\chi^2(1) = 14.72,$   
 16  $p < .001, \phi_c = .01]$  crashes, compared with not SR-L. There were also a greater proportion of SR-L  
 17 crashes occurring at dusk, dawn, or in darkness  $[\chi^2(2) = 863.51, p < .001, \phi_c = .05]$ , between 10pm  
 18 and 6am  $[\chi^2(3) = 3399.02, p < .001, \phi_c = .10]$ , and on weekends  $[\chi^2(1) = 246.07, p < .001, \phi_c = .03]$   
 19 compared with not SR-L. Conversely SR-L had a lower proportion than expected of rear-end  $[\chi^2(1) =$   
 20  $371.44, p < .001, \phi_c = .04]$ , angle  $[\chi^2(1) = 1238.42, p < .001, \phi_c = .06]$ , and sideswipe  $[\chi^2(1) = 21.50, p <$   
 21  $.001, \phi_c = .01]$  crashes in raining conditions  $[\chi^2(3) = 35.52, p < .001, \phi_c = .01]$ , at intersections  $[\chi^2(1) =$   
 22  $772.63, p < .001, \phi_c = .05]$ , with traffic control  $[\chi^2(1) = 524.32, p < .001, \phi_c = .04]$  compared with not  
 23 SR-L.

24

25

- 1 Table 3: Characteristics of crashes for each crash category between 1<sup>st</sup> January 2000 and 31<sup>st</sup>  
 2 December 2009

Variable	≥ 100km/hr speed roads		≤ 60km/hr speed roads	
	Sleep-related	Not sleep-related	Sleep-related	Not sleep-related
<i>Crash Severity</i>	(n = 3,449)	(n = 61,756)	(n = 2,408)	(n = 303,892)
Fatal/Hospitalisation	43.5%	31.8%	27.3%	21.4%
Medical Treatment	18.5%	20.9%	21.0%	25.0%
Minor Injury	9.9%	11.1%	11.5%	14.8%
PDO	28.2%	36.2%	40.2%	38.8%
<i>Intersection</i>	(n = 3,449)	(n = 61,756)	(n = 2,408)	(n = 303,892)
No	96.5%	85.1%	73.5%	44.9%
Yes	3.5%	14.9%	26.5%	55.1%
<i>Traffic control</i>	(n = 3,449)	(n = 61,756)	(n = 2,408)	(n = 303,892)
No	99.4%	94.9%	84.8%	61.7%
Yes	0.6%	5.1%	15.2%	38.3%
<i>Lighting conditions</i>	(n = 3,449)	(n = 61,756)	(n = 2,408)	(n = 303,892)
Daylight	53.5%	70.1%	46.0%	72.5%
Dawn/Dusk	8.6%	6.6%	7.8%	5.0%
Darkness	37.9%	23.3%	46.2%	22.5%
<i>Atmospheric conditions</i>	(n = 3,449)	(n = 61,756)	(n = 2,408)	(n = 303,892)
Clear	93.1%	83.1%	92.1%	88.6%
Raining	5.4%	15.1%	7.3%	11.1%
Smoke/Dust	0.1%	0.6%	0.0%	0.1%
Fog	1.5%	1.2%	0.5%	0.3%
<i>Crash type</i>	(n = 3,449)	(n = 61,756)	(n = 2,408)	(n = 303,892)
Hit object	56.7%	26.6%	71.8%	17.0%
Other	43.3%	73.4%	28.2%	83.0%
Rear-end	5.2%	26.4%	11.4%	29.3%
Other	94.8%	73.6%	88.6%	70.7%
Head-on	7.6%	4.9%	5.7%	1.8%
Other	92.4%	95.1%	94.3%	98.2%
Angle	1.0%	10.9%	6.9%	42.4%
Other	99.0%	89.1%	93.1%	57.6%
Sideswipe	4.3%	10.0%	2.3%	4.2%
Other	95.7%	90.0%	97.7%	95.8%
Overtaken	24.4%	14.4%	1.6%	0.9%
Other	75.6%	85.6%	98.4%	99.1%
<i>Day of week</i>	(n = 3,449)	(n = 61,756)	(n = 2,408)	(n = 303,892)
Monday - Friday	63.2%	72.9%	63.3%	76.8%
Saturday - Sunday	36.8%	27.1%	36.7%	23.2%
<i>Time of day</i>	(n = 3,449)	(n = 61,756)	(n = 2,408)	(n = 303,892)
10pm to 6am	38.9%	12.3%	45.7%	9.9%
6am to 2pm	33.2%	43.6%	31.1%	42.9%
2pm to 4pm	14.0%	14.3%	9.6%	15.7%
4pm to 10pm	13.9%	29.8%	13.6%	31.6%

### 1 3.3 Multivariate analyses

2 Two sets of multivariate analysis were undertaken. First SR-H vs SR-L and second SR-L vs not SR-L  
3 crashes. Table 4 outlines all the odds ratios, confidence intervals, and significance level for each  
4 variable in each comparison.

#### 5 3.3.1 Low speed sleep-related crashes vs. high speed sleep-related crashes

6 With all variables included in the logistic regression, the model was statistically significant,  $\chi^2(30) =$   
7 1498.75,  $p < .001$  (Nagelkerke  $R^2 = .36$ ).

8 The presence of intersections and traffic control had greater odds of being a SR-L crash compared to  
9 a SR-H crash. In contrast, heavy vehicles, carrying passengers, serious outcome and vehicle  
10 overturned had lower odds of being a SR-L crash compared to a SR-H crash. There was no difference  
11 between SR crashes in either speed zone for any other factor.

#### 12 3.3.2 Low speed sleep-related crashes vs low speed not sleep-related crashes

13 With all variables in the logistic regression, the model was statistically significant,  $\chi^2(30) = 4705.89$ ,  $p$   
14  $< .001$  (Nagelkerke  $R^2 = .22$ ).

15 Compared to not SR-L, the following factors had greater odds of being associated with a SR-L crash:

- 16 • Hit object crash,
- 17 • Rear-end,
- 18 • Head-on,
- 19 • Sideswipe and
- 20 • Overturned.

21

22 In contrast, 12 factors had lower odds of being a SR-L crash compared to not SR-L crash:

- 23 • Males
- 24 • Motorcyclists

- 1      • Heavy vehicles
- 2      • Unlicensed
- 3      • Illegal BAC
- 4      • Minor injury/property damage only
- 5      • Weekday
- 6      • Intersections
- 7      • Carrying passengers
- 8      • Between 6am and 10pm

9

10    Age, presence of traffic control, and angle of crash did not differ between SR-L and not SR-L.

11

1 Table 4: Logistic regression odds ratios, confidence intervals, and significance level for each variable  
 2 compared between SR-L vs SR-H and SR-L vs Not SR-L.

		Sleep-related on $\leq 60\text{km/hr}$ speed roads					
		Sleep-related on $\geq 100\text{km/hr}$ speed roads			Not sleep-related on $\leq 60\text{km/hr}$ speed roads		
		OR <sup>1</sup>	95% CI	p	OR <sup>1</sup>	95% CI	p
Gender	Female	1.00	Referent		1.00	Referent	
	Male	1.05	0.84 – 1.32	.476	<b>0.75</b>	<b>0.63 – 0.90</b>	<b>&lt; .001</b>
Age groups	16-24	1.32	0.86 – 2.02	.031	1.08	0.76 – 1.54	.480
	25-59	1.39	0.98 – 2.07	.009	1.22	0.90 – 1.67	.030
	60 and over	1.00	Referent		1.00	Referent	
Licence level	Open	1.00	Referent		1.00	Referent	
	Provisional	0.99	0.73 – 1.35	.929	0.96	0.75 – 1.23	.612
	Learner	1.49	0.82 – 2.70	.028	0.77	0.49 – 1.22	.059
	Unlicensed	1.15	0.72 – 1.82	.334	<b>0.53</b>	<b>0.37 – 0.77</b>	<b>&lt; .001</b>
Vehicle type	Car	1.00	Referent		1.00	Referent	
	Motorcycle	1.20	0.30 – 4.80	.659	<b>0.04</b>	<b>0.01 – 0.12</b>	<b>&lt; .001</b>
	Heavy Vehicle	<b>0.41</b>	<b>0.25 – 0.67</b>	<b>&lt; .001</b>	0.64	0.41 – 1.02	.002
No. of occupants	One	1.00	Referent		1.00	Referent	
	More than one	<b>0.50</b>	<b>0.39 – 0.63</b>	<b>&lt; .001</b>	<b>0.45</b>	<b>0.37 – 0.55</b>	<b>&lt; .001</b>
Illegal BAC*	No	1.00	Referent				
	Yes	1.17	0.82 – 1.67	.158	<b>0.30</b>	<b>0.23 – 0.40</b>	<b>&lt; .001</b>
Severity	Fatal/hospitalised	1.00	Referent		1.00	Referent	
	Medical treatment	<b>1.56</b>	<b>1.18 – 2.05</b>	<b>&lt; .001</b>	0.83	0.67 – 1.05	.009
	Minor injury	<b>1.54</b>	<b>1.09 – 2.16</b>	<b>&lt; .001</b>	<b>0.70</b>	<b>0.53 – 0.92</b>	<b>&lt; .001</b>
	Property damage	<b>1.83</b>	<b>1.44 – 2.32</b>	<b>&lt; .001</b>	<b>0.60</b>	<b>0.49 – 0.73</b>	<b>&lt; .001</b>
Intersection	No	1.00	Referent		1.00	Referent	
	Yes	<b>5.90</b>	<b>3.90 – 8.90</b>	<b>&lt; .001</b>	<b>0.61</b>	<b>0.48 – 0.76</b>	<b>&lt; .001</b>
Traffic-control	No	1.00	Referent		1.00	Referent	
	Yes	<b>7.48</b>	<b>3.19 – 17.53</b>	<b>&lt; .001</b>	1.03	0.78 – 1.35	.719
Day of week	Weekday	1.00	Referent		1.00	Referent	
	Weekend	1.06	0.86 – 1.30	.388	<b>0.78</b>	<b>0.66 – 0.93</b>	<b>&lt; .001</b>
Time of day	10pm to 6am	1.00	Referent		1.00	Referent	
	6am to 2pm	0.85	0.55 – 1.33	.238	<b>0.31</b>	<b>0.21 – 0.44</b>	<b>&lt; .001</b>
	2pm to 4pm	0.66	0.40 – 1.10	.007	<b>0.29</b>	<b>0.19 – 0.44</b>	<b>&lt; .001</b>
	4pm to 10pm	0.81	0.58 – 1.14	.042	<b>0.18</b>	<b>0.14 – 0.23</b>	<b>&lt; .001</b>
Hit object	No	1.00	Referent		1.00	Referent	
	Yes	1.47	0.36 – 5.93	.366	<b>50.0</b>	<b>14.29 – 99.99</b>	<b>&lt; .001</b>
Rear-end	No	1.00	Referent		1.00	Referent	
	Yes	2.82	0.67 – 11.92	.018	<b>4.54</b>	<b>1.49 – 14.29</b>	<b>&lt; .001</b>
Head-on	No	1.00	Referent		1.00	Referent	
	Yes	2.02	0.48 – 8.54	.108	<b>33.33</b>	<b>10.00 – 99.98</b>	<b>&lt; .001</b>
Angle	No	1.00	Referent		1.00	Referent	
	Yes	2.28	0.45 – 11.58	.095	2.00	0.64 – 6.25	.045
Sideswipe	No	1.00	Referent		1.00	Referent	
	Yes	0.98	0.22 – 4.43	.960	7.14	<b>2.08 – 25.00</b>	<b>&lt; .001</b>
Overturned	No	1.00	Referent		1.00	Referent	
	Yes	<b>0.12</b>	<b>0.03 – 0.54</b>	<b>&lt; .001</b>	<b>20.0</b>	<b>5.88 – 99.91</b>	<b>&lt; .001</b>

3 <sup>1</sup> Adjusted odds ratios

4 \*Illegal BAC = >0.049 for Open licence holders, >0.00 for provisional licence holders

5 Statistically significant results are in bold

## 1 4 Discussion

2 The current work considered all the crashes reported to the police on high speed ( $\geq 100$ km/h) and  
3 low speed ( $\leq 60$ km/h) roads, over a 10 year period. Results demonstrate that SR crashes are not  
4 confined to high speed roads. In terms of absolute numbers of SR crashes in the speed zones of  
5 interest, 41.1% of all police attributed SR crashes occurred on  $\leq 60$ km/h roads. To date, driver  
6 sleepiness research and road safety policy have predominantly focused on high speed roads, for  
7 example, experimental driving simulator studies most often use motorway driving scenarios (e.g.  
8 Horne and Reyner 1996, Anund *et al.* 2008, Filtner *et al.* 2012). This resolute methodological focus  
9 has resulted in a lack of understanding of the role of driver sleepiness and associated impairments  
10 on low speed roads, where a substantial proportion of SR crashes occur. Therefore, it is unknown  
11 whether the research knowledge being applied to mitigate driver sleepiness is relevant for two-fifths  
12 of the SR crashes. Further research is necessary to understand the impact of sleepiness on low speed  
13 driving performance and its association with crashes.

14 When considering only low speed crashes, SR crashes result in more severe outcomes than did not-  
15 SR crashes. This distinction of severity remains when all factors are controlled for in logistic  
16 regression, where minor injury/property damage only crashes are at lower odds of being SR-L  
17 compared with not SR-L. This result provides evidence that low speed SR crashes warrant specific  
18 investigation. This is important because they occur in densely populated areas, exposing a greater  
19 number of people to risk and have more severe outcomes than not-SR crashes on the same low  
20 speed roads. The increased prevalence of high severity outcomes associated with SR crashes has  
21 been reported by others when considering only high speed zones (Connor *et al.* 2002). It is likely  
22 that the higher severity of SR crashes is as a result of the failure of the driver to react, rather than  
23 due to a slowed reaction. This is consistent with observations of no signs of braking as another  
24 common feature of SR crashes (Horne and Reyner 2001). When compared to other driver  
25 impairment related crashes, e.g. those associated primarily with alcohol or drugs, it is perhaps  
26 unsurprising that SR crashes tend to have more severe outcomes. While a drunk or drugged driver

1 may have a slowed reaction time, the reaction time of sleep deprived individuals is characterised by  
2 prolonged lapses, with no reaction at all (Lim and Dinges 2008). Therefore, a non-reactive sleepy  
3 driver is likely to enter a crash at the same speed they were previously traveling, without braking, as  
4 opposed to their drunk counterpart who may brake late. The greater severity of SR crashes in low  
5 speed zones may also be influenced by the greater proportion of head-on collisions. Head-on  
6 crashes have the potential to be more severe due to the input of opposing kinetic energy by both  
7 objects compared to other crash outcomes. The serious nature of SR-L crashes and the  
8 overrepresentation of head-on collision suggests that SR-L crashes should be an important focus  
9 area for improving road safety.

10 There was no difference in the proportion of drink drivers between SR-L and SR-H categories;  
11 however, SR-L crashes were more likely to involve alcohol above the legal limit (> 0.49 BAC for open  
12 licence holders and > 0.00 BAC for provisional licence holders) than were not SR-L crashes. Previous  
13 research has demonstrated that low doses of alcohol interact with sleepiness to cause greater  
14 impairment than either alone, and greater impairment than their simple additive effects would  
15 predict (Horne *et al.* 2003, Banks *et al.* 2004). The combination of sleepiness and alcohol appears to  
16 be particularly dangerous in low speed zones. However, when all other factors are controlled for in  
17 the logistic regression analysis the relationship reverses, and the involvement of illegal BAC is at  
18 lower odds in SR-L crashes than not SR-L crashes. This suggests there may be another unknown  
19 factor that is influencing the relationship between sleep and alcohol related crashes. Further research  
20 is needed to identify factors which influence the interaction between alcohol and sleepiness in low  
21 speed zones.

22 Collisions with a stationary object or running off the road have been identified as common outcomes  
23 of SR crashes (Horne and Reyner 2001). In the current analysis, the crash outcome of hitting a  
24 stationary object was more common in SR-L crashes than in SR-H crashes, and more common in SR-L  
25 crashes than not SR-L crashes. When all other factors were controlled for in the logistic regression,



1 collision with a stationary object remained more common in SR-L crashes than in not SR-L crashes,  
2 but was no longer different between SR-H and SR-L crashes. Overall, this crash outcome appears to  
3 be common to both high and low speed SR crashes and a distinct feature of SR-L compared to not  
4 SR-L crashes. This finding adds support to the suggestion that collision with a stationary object may  
5 be considered a feature with which SR crashes could be identified (Crummy *et al.* 2008).

6 To further understand the nature of SR-L crashes, comparison was made to SR-H crashes. Sleep  
7 crashes on  $\geq 100$ km/h roads were selected as a reference group because previous work has  
8 identified that SR crashes are prevalent in high speed zones (Philip *et al.* 2014) and most is known  
9 about SR driving impairment on high speed roads as experimental research using both simulators  
10 and on-road protocols has focused on these speeds. The current work supports the value of  
11 investigating high speed SR crashes as SR crashes were found to be 7.5 times more likely on high  
12 speed roads. SR crashes also make up a greater proportion of high speed than low speed crashes.  
13 However, this distribution is influenced by the greater overall frequency of crashes on low speed  
14 roads. SR crashes on high speed roads remain a leading road safety problem which is imperative to  
15 address. Nevertheless, the current work also demonstrates that SR crashes are not confined to high  
16 speed roads. Therefore, any resources aimed at reducing the number of SR crashes should not  
17 overlook low speed roads. Low speed zones are commonly applied in highly populated areas.  
18 Therefore, for every crash which occurs in a low speed area there are a greater number of people  
19 who could potentially be impacted compared with an equivalent crash in a high speed zone.

20 The current work demonstrates that SR-L crashes are similar to SR-H crashes in that young (16-24y)  
21 males are over represented, and the odds of crash outcome (hitting object, head-on, rear-end, angle  
22 crash, sideswipe) are the same. This finding identifies a need to target interventions for reducing  
23 driver sleepiness towards young drivers specifically, and in all road environments. Road safety  
24 strategies for reducing driver sleepiness are often passive, and targeted at the general population  
25 e.g. road-side signage advising drivers to take a break. These interventions do not specifically target

1 the demographic most at risk (young novice drivers), nor do they address the underlying cause of  
2 sleepiness (insufficient sleep). Previous research has demonstrated that sleep loss is prevalent in  
3 young people, for example, due to social (Breslau *et al.* 1997) and developmental (Brendel *et al.*  
4 1990) factors. Furthermore, the driving performance of younger adults is more impaired following  
5 sleep loss than that of older drivers (Filtness *et al.* 2012). All of which demonstrate the importance of  
6 targeting driver sleepiness mitigation strategies towards this group.

7 For the majority of variables SR-L and SR-H crashes were very similar in characteristic. Three notable  
8 exceptions were, the involvement of a heavy vehicle, serious outcomes, and carrying passengers.  
9 This is likely to be a reflection of the way in which high speed roads are used, rather than an  
10 important difference between SR-L and SR-H per se. There are likely to be a disproportionate  
11 number of heavy vehicles traveling on high speed zone roads compared to low speed zone roads as  
12 freight transport often involves the movement of goods between urban areas. Therefore, it is  
13 possible that this finding is a reflection of exposure rather than an explicit difference between SR  
14 crash characteristics of low and high speed. Similarly, the greater severity of SR-H crashes is likely a  
15 reflection of the crashed vehicle having been traveling at a higher speed at the point of impact than  
16 SR-L. One countermeasure commonly proposed to mitigate driver sleepiness is to alternate between  
17 drivers (Department of Transport and Main Roads, 2010). Many of those drivers who had a SR-H  
18 crash had a passenger with them, although it is not known whether the passenger would have been  
19 able to take over driving; it is a possible option which could have reduced the chance of SR crash.  
20 Education campaigns may wish to focus on this area with an aim of empowering drivers to feel able  
21 to ask passengers to take over the driving task and to encourage passengers to offer to drive.  
22 However, it should be acknowledged that for young drivers, carrying a peer passenger can have a  
23 negative influence on safe driving behaviour (Curry *et al.*, 2012). As young drivers are the most likely  
24 to have a SR crash, caution should be taken on the appropriateness of recommending alternating  
25 drivers as a countermeasure to sleepiness for this group. Drivers who have SR crashes on low speed  
26 roads are less likely to have the option to alternate drivers. The absence of a passenger may also

1 suggest a difference in purpose of journeys which end in SR-L than SR-H crashes. For example,  
2 survey data suggests that SR-L crashes are more likely to occur during commuting (Armstrong *et al.*  
3 2013). Therefore, education campaigns would have greatest chance of success if they target  
4 countermeasures which were most appropriate for the particular situation e.g. seeking alternative  
5 transport options for shift workers traveling in low speed zones.

6 Direct comparison between SR-L and SR-H crashes demonstrated SR-L crashes to be more prevalent  
7 than would be expected at night (10pm-6am). Time of day has a strong influence on driving  
8 performance (Lenné *et al.* 1997, Matthews *et al.* 2012), with greater impairment reported during  
9 circadian-mediated periods of low arousal. However, these time-of-day studies have been  
10 conducted using high speed environments and it is not clear whether the same variation in driving  
11 performance would be observed under the more complex, and dynamic driving scenarios common  
12 to low speed roads. Although time-of-day differences were initially apparent, when all other factors  
13 are controlled for within the logistic regression analysis, night time driving no longer has a significant  
14 influence on SR-L. Future research may wish to consider time-of-day effects in low speed  
15 environments for sleep deprived drivers and seek to understand what factors contribute towards  
16 and are protective of SR crashes. For example, there may be particular implications for shift workers  
17 who commute on these roads during night time hours.

18 Overall, the proportion of SR crashes (5.3% high speed crashes, 0.7% of low speed crashes) is lower  
19 than might be expected from case control studies, which suggest that approximately 19% of all fatal  
20 and severe road crashes can be attributed to sleepiness (Connor *et al.* 2002). While it is possible that  
21 local safety campaigns have been effective at reducing the number of drivers who drive when  
22 sleepy, it should be noted that the most likely reason for the difference is that the current analysis  
23 was conducted on data from police data rather than a case control study. Therefore, it is likely that  
24 the current results are an underestimation of the total number of SR crashes. USA estimates suggest  
25 that SR fatal crashes may be underestimated by as much as 350%, due to missing data or

1 misclassification by attending enforcement officers (Tefft 2012). There may be several reasons for  
2 this, first, police officers lack an accurate objective measure of sleepiness and self-reported difficulty  
3 to identify sleepiness as a crash causal factor (Radun *et al.* 2013). Second, in a previous study we  
4 have found that of drivers who self-report having had a SR incident in the previous 5 years, only 45%  
5 report that the police were involved (Armstrong *et al.* 2013).

6 The current work does not seek to evaluate police methods for identifying SR crashes. Rather, the  
7 objective was to quantify the characteristics of SR crashes in the existing police data. However, given  
8 the reported police difficulty in identifying SR crashes (Radun *et al.* 2013) future research should  
9 consider how police reporting of SR crashes could be improved. For example, one approach which  
10 may assist police officers in accurately determining sleepiness would be to include in this database  
11 the mandatory collection of information estimating how long drivers have been awake, how long  
12 their last sleep period was and how long they had been driving prior to the crash. These variables are  
13 not currently recorded within the police crash database so it was not possible for them to inform this  
14 analysis. However, this does not mean that this information did not form part of the investigation  
15 when police determine the crash casual factors. Similarly, while the police may consider sleep  
16 disorders as a potential contributor to driver sleepiness, potentially clinically relevant information  
17 for sleep disorders e.g. weight and reports of snoring are not available in the analysed data set  
18 because they are not standard variables recorded in the database. The current work considers only  
19 the standard police crash investigation information held by the Queensland State Government, it  
20 does not consider the specifics of each investigation; this information is unknown to the authors.

21 Queensland authorities (independent to police) are aware of the potential for underestimating SR  
22 crashes and apply a proxy definition post-hoc to all crash data. This definition states that sleepiness  
23 is a contributing factor in all single-vehicle crashes on  $\geq 100$ km/h speed roads which occur between  
24 2pm to 4pm and 10pm to 6am, or where a vehicle leaves the roadway with the driver not  
25 attempting to avoid the crash. The use of this definition is not considered in this work. Using a proxy

1 definition such as this increases the proportion of crashes identified as SR; however, there is a  
2 current lack of evaluations verifying the accuracy of this approach. The implications for using a proxy  
3 definition of SR crash on estimates of sleep involvement in high speed zone crashes in Queensland is  
4 discussed in our previous work (Filtner *et al.* in press).

5 The limitations of the current work should be acknowledged. All crash data were from police report.  
6 The accuracy of police at identifying the involvement of fatigue or sleepiness in each crash was not  
7 considered. There is potential for inconsistency in reporting between police officers particularly for  
8 differences between serious and non-serious crashes. Additionally, the magnitude of under  
9 reporting may not be consistent across the high and low speed zone crashes. For example, if police  
10 officers are aware that SR crashes are more common in high speed zones they may be more actively  
11 looking for this causal factor in this environment, therefore SR-L crashes may be more  
12 underestimated than SR-H. The factors used by police when identifying SR crashes were not  
13 considered. It is possible that the police use some of the characteristics examined during the analysis  
14 to inform their decision, this may introduce bias to the findings.

15 Serious crashes (fatal or serious injury) are attended by the Forensic Crash Investigation unit, where  
16 specially trained officers will seek detailed information about the circumstances during and prior to  
17 the crash which can include the extent of prior sleep. In contrast, enforcement officers attending  
18 non-serious crashes are not as highly trained and have fewer resources available to them than do  
19 the officers of the Forensic Crash Investigation unit. Therefore, it is possible that SR identification in  
20 less serious crashes may not be as accurate. This has implications for the finding that SR-L crashes  
21 result in more severe outcomes than not SR-L crashes. It is possible that the Forensic Crash  
22 Investigation unit who only attend serious crashes may be more likely to identify SR causal factors  
23 than the officers attending a non-serious crash. Furthermore, data are only from crashes which  
24 police attended and as such results may not be representative of crashes which are not reported to

1 the police. Finally, the data were only from a single state; it is not known how comparable findings  
2 are to other jurisdictions.

### 3 **4.1 Conclusion**

4 In conclusion, this study demonstrates that driver sleepiness is not restricted to high speed,  
5 motorway driving. SR-L crashes are numerous and represent 41% of all SR crashes. While SR-L  
6 crashes have largely similar characteristics to SR-H crashes, they warrant specific investigation  
7 because they occur in densely populated areas, exposing a greater number of people to risk and are  
8 notably different to not-SR crashes occurring in low speed zones. In particular, SR-L crashes are more  
9 serious than not SR-L crashes, and are more likely to involve collision with a stationary object. Young  
10 males (16-24y) are overrepresented in SR-L crashes compared to not SR-L crashes. This age group  
11 appear to be particularly at risk of SR crash. These characteristics do not differ between SR-H and  
12 SR-L crashes, suggesting that these crash features are directly related to the presence of sleepiness  
13 and are independent of speed zone. Interventions to reduce driver sleepiness should consider  
14 specifically targeting young male drivers and emphasise the potential for SR crash in low as well as  
15 high speed areas. Previous research has demonstrated that sleepiness impairs driver performance  
16 during monotonous motorway driving; however, sleepiness is a biological need that remains with  
17 the driver as they transition between high and low speed roads. Therefore, sleepiness is still present  
18 and has the same potential to impair driving performance in low speed environments. The current  
19 focus of driver sleepiness awareness campaigns on high speed driving has the potential to mislead  
20 the general public into believing that sleepiness is not a problem in low speed zones. Without  
21 accurate sleepiness detection technologies it is vital that drivers take responsibility for their own  
22 sleepiness and take action when necessary. Experimental evidence has demonstrated that drivers  
23 are able to identify sleepiness if directed to look for it (Reyner and Horne 1998, Horne and Baulk  
24 2004, Williamson *et al.* 2014). Drivers should be advised that lack of sleep will lead to sleepiness.  
25 Sleepiness will impair their driving performance and will put their safety and the safety of others at  
26 risk. They should learn to identify this risk before any and every drive. .

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