



## Are there sex differences in crash and crash-related injury between men and women? A 13-year cohort study of young drivers in Australia

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### ABSTRACT

**Background:** Young men have long been known to be disproportionately impacted by road crash and crash-related injury compared to young women and older drivers. However, there is limited insight into how sex differences in crash and crash-related injury changes over time as men and women get older and gain more driving experience. To explore sex differences in crash and crash-related injury, we undertook a sex disaggregated analysis in a large longitudinal cohort of over 20,000 young drivers in New South Wales, Australia, for up to 13 years after they first attained their independent car driver licence.

**Methods:** DRIVE Study survey data from 2003–04 were linked with police, hospital and deaths data up to 2016. Sex differences were analysed using cumulative incidence curves investigating time to first crash and in negative binominal regression models adjusted for driver demographics and crash risk factors.

**Results:** After adjusting for demographics and driving exposure, compared with women, men had 1.25 (95% CI 1.18–1.33), 2.07 (1.75–2.45), 1.28 (95% CI 1.13–1.46), 1.32 (95% CI 1.17–1.50) and 1.59 (95% CI 1.43–1.78) times higher rates of any crash, single vehicle crash, crash on streets with a speed limit of 80 km/h or above, crash in wet conditions and crash in the dark, respectively. By contrast, men were less likely to be involved in crashes that resulted in hospitalisation compared to women 0.73 (95% CI 0.55–0.96).

**Conclusions:** Young men are at increased risk of crash, and this risk persists as they get older and gain more driving experience. Despite lower risk of crash, women are at higher risk of crash related injury requiring hospitalisation. These differences in men's and women's risk of crash and injury signal the need for better understanding of how sex and/or gender may contribute to risk of crash and injury across the life-course.

### Background

Globally, more men die from injury than women (Sorenson, 2011). Among young people, transport injury is a leading cause of death and disability, which disproportionately impacts young men, with lifelong implications for future health due to permanent disability and reduced opportunity for education, employment and recreation (James et al., 2020; Mokdad et al., 2016; World Health Organisation, 2018). The over-representation of young people, and in particular young men, in road crashes has persisted despite improvements in road safety and

implementation of policies targeting young drivers, including graduated driver licensing schemes (McCartt & Teoh, 2015).

Increases in risk-taking behaviour during adolescence likely underlie the disproportionate burden of transport injury among young people, including non-use of restraints (Chen et al., 2010; Jiménez-Mejías et al., 2014), alcohol impaired driving (Kelley-Baker & Romano, 2010; Tsai et al., 2010) and speeding (Kelley-Baker & Romano, 2010; Oviedo-Trespalacios & Scott-Parker, 2018), as well as other known risk factors such as inappropriate driver training (Beanland et al., 2013) and limited on-road experience (McCartt et al., 2009). While inexperience

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contributes to young driver crashes, this does not account for higher rates of crashes and transport related mortality and morbidity in young men compared to young women.

Much of the literature exploring sex differences in crash involvement has focused on the intersection of crash conditions and driver behaviour (Al-Balbissi, 2003; Amarasingha & Dissanayake, 2014; Bener & Crundall, 2008; Jiménez-Mejías et al., 2014; Jones, 2017; Kelley-Baker & Romano, 2010; Oviedo-Trespalacios & Scott-Parker, 2018; Romano et al., 2008). These studies show that sex differences in driving behaviour may account for much of the difference in crash involvement, with men driving further distances and more likely to engage in risky driving behaviours than women, for example, men tend to be over-represented in crashes associated with risky driving behaviours such as: speeding (Kelley-Baker & Romano, 2010); violations and driver faults due to lack of attention and impatience (Al-Balbissi, 2003); and alcohol impaired driving (Amarasingha & Dissanayake, 2014; Kelley-Baker & Romano, 2010; Tsai et al., 2008, 2010).

While men are at greater risk of crash, studies from the United States have shown that women are increasingly involved in fatal crashes, which has been attributed to trends in increased driving exposure and risk-taking behaviours, particularly among younger women (Romano et al., 2008; Tsai et al., 2010). However, much of this research exploring sex differences relies on self-reported crash data, which may underestimate the rate of crash (Bener & Crundall, 2008; Jiménez-Mejías et al., 2014; Oviedo-Trespalacios & Scott-Parker, 2018). While other studies used routinely collected crash data, they were not able to explore associations with individual factors of interest such as risk perception and personality traits (Al-Balbissi, 2003; Amarasingha & Dissanayake, 2014; Jones, 2017; Kelley-Baker & Romano, 2010; Romano et al., 2008; Tsai et al., 2010).

These limitations can be overcome in prospective research designs where known risk factors for crash involvement and other factors underpinning risky behaviours can be collected at the study onset and crash involvement followed over time. The DRIVE study (Ivers et al., 2006), a large longitudinal cohort of over 20,000 young novice drivers from New South Wales (NSW) Australia takes this approach. The DRIVE study is unique in that information collected at baseline includes comprehensive measures of participant's demographics, driving experience, driver training, risk perception, driver behaviour, lifestyle habits (including alcohol and drug use), sensation seeking, mental health and sleep habits. This provided rich data that has been linked with routinely collected crash, hospital, and mortality data, thereby overcoming shortcomings in self-report in determining risk factors crash and injury. The findings from the DRIVE cohort identified important crash risk factors for novice drivers during the first two years of driving, including residence in a rural area, low socio-economic status, poor sleep habits as well as engaging in risky driving behaviours and other risky behaviours such as self-harm (Boufous et al., 2010; Ivers et al., 2009; Martiniuk et al., 2013; Martiniuk et al., 2009). However, to date we have not specifically investigated differences between men and women in the DRIVE cohort to determine if there are sex differences in either rate or type of crash or crash-related injury.

The sex and/or gendered dimensions of people's experiences are important, yet despite increasing awareness, research efforts are hampered by use of inconsistent terminology, insufficient data resources and conflation of sex and gender (Day et al., 2016). Sex and gender are interrelated, yet conceptually distinct. Sex refers to biological characteristics that see people assigned as male, female or intersex. While gender is non-binary and not static, it is the "socially constructed roles, behaviours, expressions and identities of girls, women, boys, men, and gender- and sexually-diverse people. It influences how people perceive themselves and others, how they act and interact and the distribution of power and resources in society" (Canadian Institutes of Health Research, 2018, p. 6). While gender is often poorly represented in health research, reporting biological sex should be fairly straightforward, yet up to 11% of published novice driver research does not report sex in terms of

proportion of male and female participants (Scott-Parker & Senserrick, 2017). Recent re-linkage of the DRIVE study with 13-year follow-up allows in depth analysis of sex differences. Accordingly, we undertake a sex disaggregated analysis in the DRIVE cohort, in which we aim to investigate sex differences in crash and crash-related injury among 20,000 drivers for up to 13 years after they first attained their independent car driver licence in NSW. Our analysis is guided by the following research questions: 1) Do men and women in the DRIVE cohort have different rates of crash? 2) Do these differ for different types of crash?

## Methods

### Study area

This study was undertaken in NSW, the most populous state in Australia with 7.5 million residents (1.7 million (23%) aged 20–35) at the 2016 census (Australian Bureau of Statistics, 2018a). Of these, 5 million people hold a driver licence for a car and there were 4.28 million registered passenger vehicles in NSW in 2018 (Australian Bureau of Statistics, 2018b; NSW Transport Roads and Maritime Services, 2019).

### Data sources

We used data from 20,806 participants from the DRIVE Study, a 2003/04 New South Wales survey of newly licenced young drivers. Data collection and the DRIVE cohort have been described in detail elsewhere (Ivers et al., 2006). Briefly, drivers aged 17–24 years holding their first independent motor vehicle driver license from NSW Australia were eligible to participate. Information on driver demographics, driving exposure, driving experiences and training and known and hypothesized crash risk factors was collected.

The DRIVE survey data were linked with crash data from the NSW Centre for Road Safety, hospital data from the NSW Admitted Patient Data Collection and deaths data from the NSW Registry of Births Deaths and Marriages and the Australian Bureau of Statistics cause of death data up to 2016. The NSW Centre for Health Record Linkage ([www.cherel.org.au](http://www.cherel.org.au)) performed probabilistic linkage of the data and supplied de-identified data sets for analysis.

The NSW Centre for Road Safety Crash Link system provides information on all police reported road crashes that occur on NSW classified and local roads. The data contains among other information on the circumstances and location of the crash, road user movement, road conditions, person involved and the crash outcome. The Admitted Patient Data Collection includes records for all hospital separations (discharges, transfers and deaths) from all NSW public and private hospitals and day procedure centres, coded according to the Australian modification of the International Statistical Classification of Diseases and Related Problems, 10th revision (ICD-10-AM) (National Centre for Classification in Health, 2008). The NSW Registry of Births, Deaths and Marriages contains information on all deaths in NSW. The Australian Bureau of Statistics cause of death data includes information derived from the deaths certificate or coronial report on the cause of deaths.

### Variables in the analysis

The outcome measures were total number of crashes (i.e. police recorded crash, crash resulting in hospitalisation or death), crash related hospitalisations or death, single vehicle crashes, crashes on streets with speed limits of 80 km/h or more, crashes in wet conditions and crashes in the dark that occurred during follow up (2003–2016). We only included crashes related to vehicles that the study participants could legally drive with a NSW car licence, and hospitalisations where the study participant was identified as the driver of a car in the hospital data (ICD10-AM V40–V59 0.0 and .5). The total number of crashes was derived from linkage of the cohort data with the crash, hospital and death data. Crash related hospital admissions on the same day or within

one day of a record in the police reported crash data were considered the same crash. The exposure under investigation was self-reported sex<sup>1</sup> recorded at the time of the baseline survey.

Other variables in the analysis were measures of driver demographic characteristics (age, geographical remoteness and socioeconomic status of area of residence and country of birth), drug and alcohol use (cannabis, other drug and alcohol use), driver training and experience (supervised driving hours, months on learner licence, number of attempts on learner licence, self-rated driving ability, months between independent (provisional) driver licence and study entry, involvement in crash before study), driving behaviour and attitude (risk taking behaviour, risk perception, sensation seeking) and driving exposure (average weekly driving) (Table 1) (Ivers et al., 2006). Selection of these variables included in the analysis was informed by previous analyses of DRIVE data and international studies on risk factors for crash (Boufous et al., 2010; Chen et al., 2010; Hasselberg & Laflamme, 2003; Hasselberg, Vaez, & Laflamme, 2005; Ivers et al., 2009; Martiniuk et al., 2009; Talbot et al., 2016) Area level socioeconomic status was derived from the Australian Bureau of Statistics 2001 area level Socio-Economic Indexes for Areas index of education and occupation (SEIFA index) (Trewin, 2001). Geographical remoteness of residence was classified using the Accessibility/Remoteness index of Australia, grouped into three groups (metropolitan, inner and outer regional, remote and very remote) (Trewin, 2004). Both indices were matched to participants by postal area at study recruitment.

*Imputation of missing data and statistical analysis*

Although completeness of recording of survey variables used in the analysis was high (93–100%), the joint percentage of missing data across all variables in the multivariate analysis was 15%. Missing values in the models were thus imputed using chained equations in Stata with 30 imputation cycles (Royston & White, 2011).

The association between sex and car crash was examined by cumulative incidence curves investigating time to first crash and quantified using negative binominal regression models. Time between survey and end of follow up (31<sup>st</sup> December 2016) was included as an offset variable in the regression models to account for different lengths of exposure. Participants who died during follow up (n = 72) were censored at the date of death.

The initial regression model adjusted for demographic factors and driving exposure (Model 1), the influence of known crash risk factors on differences in crash between men and women was investigated by adding measures of alcohol and drug use (Model 2), risk taking behaviour, perception and sensation seeking (Model 3), driver training and experience (Model 4) and all of these measures combined (Model 5). Confounding variables were collected at baseline and included age (17, 18–19, or 20–25 years), country of birth, socioeconomic status using SEIFA index, remoteness of area of residence (metropolitan, inner regional, or outer regional/remote), and average driving hours per week.

The percentage excess risk of crash in men compared with women that was due to differences in risk factor levels was calculated as 100  $([RR_c - RR_A] / [RR_c - 1])\%$  where  $RR_c$  and  $RR_A$  are, respectively, the rate ratios for crash comparing men with women adjusted for confounding (Model M1) and after (further) adjustment for each risk factor alone and then for all risk factors combined (Woodward et al., 2003).

<sup>1</sup> We use the terms “men” and “women” in reporting findings from the DRIVE cohort. In the DRIVE survey, participants were asked: “Are you male or female?” They were not instructed to self-report their biological sex, and the options were simply “male” and “female” with no other alternatives.

**Table 1**  
DRIVE Cohort characteristics, NSW, Australia 2003–2016.

Characteristic	Value	Women (n =	Men (n =
		11357)	9949)
		n (%)	n (%)
Age (years)	17	4898 (43.13)	5230 (55.35)
	18–19	4490 (39.54)	3251 (34.41)
	20–25	1969 (17.34)	968 (10.24)
Country of birth	Australia & New Zealand	9876 (86.96)	8007 (84.74)
	Other	1306 (11.50)	1247 (13.20)
	Missing	175 (1.54)	195 (2.06)
Remoteness	Metro	8339 (73.43)	7124 (75.39)
	Inner regional	2471 (21.76)	1928 (20.4)
	Outer regional/remote	547 (4.82)	397 (4.2)
Attempts at driver test	1	7460 (65.69)	6028 (63.8)
	2	2679 (23.59)	2283 (24.16)
	3 or more	1187 (10.45)	1101 (11.65)
Time on Learner Licence	Missing	31 (0.27)	37 (0.39)
	<1 year	3993 (35.16)	3941 (41.71)
	1–1.5 years	3874 (34.11)	3542 (37.49)
Crash before study	>1.5 years	3453 (30.4)	1922 (20.34)
	Missing	37 (0.33)	44 (0.47)
	No	11003 (96.88)	9109 (96.4)
Marijuana smoking in last 12 months	Yes	354 (3.12)	340 (3.6)
	Never	9613 (84.64)	7668 (81.15)
	Once a month or less	1046 (9.21)	1051 (11.12)
Use of other drugs in last 12 months	2–4 times a month	180 (1.58)	220 (2.33)
	2 or more per week	118 (1.04)	179 (1.89)
	Missing	400 (3.52)	331 (3.5)
Self-rated driving ability compared to other drivers same stage	Never	10153 (89.4)	8516 (90.13)
	Once a month or less	610 (5.37)	423 (4.48)
	2–4 times a month	132 (1.16)	106 (1.12)
Risk taking	2 or more per week	44 (0.39)	51 (0.54)
	Missing	418 (3.68)	353 (3.74)
	Much better	1569 (13.82)	2165 (22.91)
Poor risk perception	Better	4698 (41.37)	4070 (43.07)
	Same	4482 (39.46)	2768 (29.29)
	Worse or much worse	216 (1.9)	126 (1.33)
Risk taking	Missing	392 (3.45)	320 (3.39)
	Low	4335 (38.17)	2521 (26.68)
	Medium	3665 (32.27)	2796 (29.59)
Poor risk perception	High	2762 (24.32)	3697 (39.13)
	Missing	595 (5.24)	435 (4.6)
	Low	4114 (36.22)	2103 (22.26)
Poor risk perception	Medium	3456 (30.43)	2696 (28.53)

(continued on next page)

**Table 1** (continued)

Characteristic	Value	Women (n =	Men (n =
		11357)	9949)
		n (%)	n (%)
Sensation seeking	High	3149 (27.73)	4149 (43.91)
	Missing	638 (5.62)	501 (5.3)
	Low	4080 (35.92)	2180 (23.07)
Alcohol audit	Medium	3439 (30.28)	2959 (31.32)
	High	3183 (28.03)	3821 (40.44)
	Missing	655 (5.77)	489 (5.18)
Professional instructor training (hours)	0–6	9968 (87.77)	7490 (79.27)
	>6	1007 (8.87)	1653 (17.49)
	Missing	382 (3.36)	306 (3.24)
Average weekly driving (hours)	0	1570 (13.82)	2090 (22.12)
	1–4	2930 (25.8)	2985 (31.59)
	5–8	2426 (21.36)	1868 (19.77)
	9+	4431 (39.02)	2506 (26.52)
Average weekly driving (hours)	0–2	2229 (19.63)	1820 (19.26)
	3–5	3558 (31.33)	2906 (30.75)
	6–9	1906 (16.78)	1374 (14.54)
	10+	3664 (32.26)	3349 (35.44)

## Results

A total of 20,806 novice drivers (54.6% women) were included in the study cohort and the mean follow up time was 13 years (SD 0.6). Most study participants were born in Australia or New Zealand (85.9%) and lived in metropolitan areas (74.3%) (Table 1). A higher proportion of women (17.3%) were aged 20–25, held a learner licence for more than 1.5 years before progressing onto an independent licence (30.4%) and had more than 9 h of professional instructor training (39.0%) compared with men (10.2%, 20.3% and 26.5%, respectively). A higher proportion of men drove 10 or more hours per week (35.4%) rated their driving ability as much better than other drivers (22.9%), had poorest risk perception (43.9%), and highest risk taking (39.1%) and sensation seeking scores (40.4%) compared with women (32.3%, 13.8%, 27.7%, 24.3% and 28.0%, respectively).

During the study period, 2125 (19.0%) women and 2124 (22.5%) men were involved in a car crash (Table 2, Fig. 1). Differences in the proportion of men and women involved in a car crash increased over time (Fig. 1). More men than women were involved in a single vehicle crash, crashed on streets with speed limits of 80 km/h or above, and in dark and wet conditions. More women (142, 1.3%) than men (85, 0.9%) were hospitalised for crash related injuries.

After adjusting for demographics and driving exposure (age, country of birth, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence and average driving per week), men had 1.25 (95% CI 1.18–1.33), 2.07 (1.75–2.45), 1.28 (95% CI 1.13–1.46), 1.32 (95% CI 1.17–1.50) and 1.59 (1.43–1.78) times higher rates of any crash, single vehicle crash, crash on streets with a speed limit of 80 km/h or above, crash in wet conditions and crash in the dark compared with women, respectively (Table 3). Adjusting for crash risk factors (drug and alcohol use, risk taking behaviours and driver training and experience) in the analysis reduced male/female rate ratios for these crashes only slightly. Compared with the analysis adjusted for confounders only, adjusting for all other risk factors reduced male/female rate ratios for

**Table 2**

Number of crash events by sex, DRIVE cohort, NSW, Australia, 2003–2016.

Variable	Category	Women (n =	Men (n =
		11357)	9949)
		n (%)	n (%)
Any crash	None	9232 (81.29)	7325 (77.52)
	1	1852 (16.31)	1744 (18.46)
	2 or more	273 (2.40)	380 (4.02)
Crash <sup>a</sup> related spital admission or deaths	None	11215 (98.75)	9364 (99.1)
	1 or more	142 (1.25)	85 (0.90)
Single vehicle crash	None	11144 (98.12)	9081 (96.11)
	1 or more	213 (1.88)	368 (3.89)
Crash on street with limit of 80 km/h or above	None	10892 (95.91)	8967 (94.9)
	1 or more	465 (4.09)	482 (5.1)
Crash in wet	None	10888 (95.87)	8926 (94.47)
	1 or more	469 (4.13)	523 (5.53)
Crash in dark	None	10821 (95.28)	8731 (92.4)
	1 or more	536 (4.72)	718 (7.6)

<sup>a</sup> These are crashes where the study participant was the driver of the vehicle and admissions for same injury within 30 days were excluded.

any crashes by 15.5%, for single vehicle crashes by 1.4%, for crashes on streets with a speed limit of 80 km/h or above by 2.5%, crashes in wet conditions by 2.5% and crash in the dark by 11.9% (Fig. 2). In comparison, men had a 0.73 (95% CI 0.55–0.96) times lower rate of crashes that resulted in hospital admissions or deaths compared with women. This difference increased by 16% (RR 0.68 (95% CI 0.51–0.91) after adjusting for risk factors in the analysis (Table 3, Fig. 2).

Further analysis of hospitalised crashes showed that there was no difference in the severity of hospitalised injuries measured as the mean probability of survival of the most severe injury (women: 96.55 (95% CI 95.35–97.74), men: 95.23 (95% CI 93.27–97.19)) and the mean total number of injuries sustained in the crash (women: 2.44 (95% CI 1.95–2.93), men: 2.66 (95% CI 2.01–3.32)) between men and women. There were no differences in the types of injuries recorded in the principal diagnosis groups between men and women, except that women had higher rates of admissions for contusions (150 per 100,000 (95% CI 87–234) compared with men (30 per 100,000 (95% CI 6–80)).

## Discussion

In this prospective cohort of novice drivers with a thirteen year follow up period, there were sex differences in crash and crash-related injury. Men had higher rates than women for all crash types apart from crashes that resulted in hospital admissions or deaths. The largest differences between men and women were observed for single vehicle crashes and crashes in the dark, with men 2.33 and 1.66 times more likely to crash, respectively. Adjusting for established and hypothesized crash risk factors reduced the sex differences crash rate ratio slightly, but substantial differences remained. These findings indicate there may be different drivers of sex differences between crash involvement and injury outcome following a crash that could not be considered in the analysis; we discuss these findings in the context of the need for increased consideration of the sex and/or gender determinants of crash and injury.

As drivers, young men have long been known to be at increased risk of crash compared to young women and older drivers (Amarasingha & Dissanayake, 2014; Jones, 2017). Our results build on these established sex differences and demonstrate that this increased risk does not diminish as men get older and gain more driving experience through the early to middle years of adulthood. In our cohort, men were at higher risk of certain types of crash and were twice as likely as women to be involved in a single vehicle crash. This affirms previous research that has identified men at higher risk of single vehicle crashes (Amarasingha & Dissanayake, 2014; Bingham & Ehsani, 2012; Brown et al., 2014; Jones, 2017; Tsai et al., 2008). A hypothesized explanation for this is that single vehicle crashes result from increased risk-taking behaviour, for example

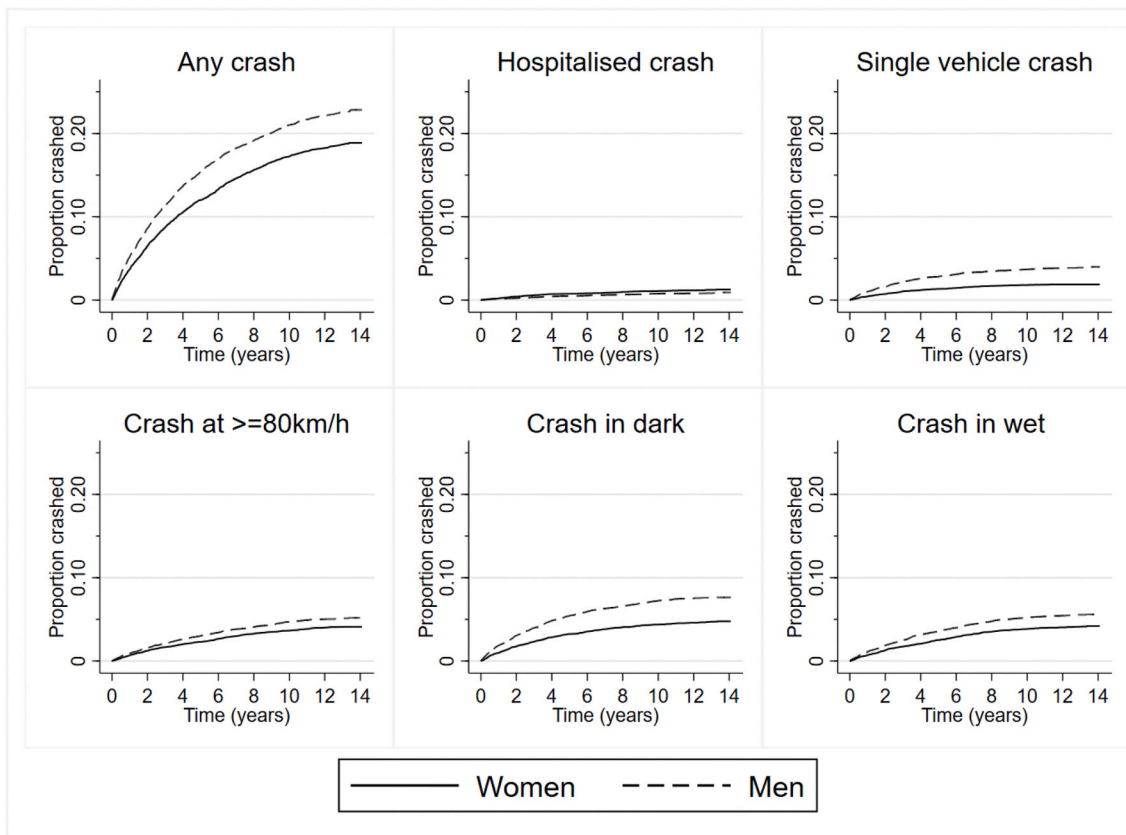


Fig. 1. Cumulative incidence curves by type of crash, DRIVE cohort, NSW, Australia, 2003–2016.

Table 3

Adjusted\* men/women rate ratio of motor vehicle crash, DRIVE cohort, NSW, Australia 2003–2016.

Model	Any crash	Hospitalised crash or deaths	Single vehicle crash	Crash at $\geq 80$ km/h	Crash in wet	Crash in dark
M0 unadjusted	1.29 (1.21–1.36)	0.71 (0.54–0.94)	2.13 (1.80–2.52)	1.29 (1.14–1.47)	1.36 (1.20–1.54)	1.66 (1.48–1.85)
M1 confounding	1.25 (1.18–1.33)	0.73 (0.55–0.96)	2.07 (1.75–2.45)	1.28 (1.13–1.46)	1.32 (1.17–1.50)	1.59 (1.43–1.78)
M2 confounding & drugs	1.25 (1.18–1.32)	0.72 (0.54–0.95)	2.04 (1.72–2.42)	1.29 (1.13–1.46)	1.33 (1.17–1.51)	1.58 (1.41–1.77)
M3 confounding & risk taking	1.22 (1.15–1.30)	0.69 (0.52–0.91)	2.01 (1.70–2.39)	1.27 (1.11–1.45)	1.29 (1.14–1.47)	1.55 (1.38–1.74)
M4 confounding & training & experience	1.24 (1.17–1.32)	0.71 (0.53–0.94)	2.09 (1.76–2.49)	1.29 (1.13–1.46)	1.33 (1.17–1.51)	1.56 (1.39–1.75)
M5 fully adjusted	1.21 (1.14–1.29)	0.68 (0.51–0.91)	2.05 (1.72–2.45)	1.28 (1.12–1.46)	1.31 (1.15–1.50)	1.52 (1.35–1.71)

\*Negative binominal regression of imputed data adjusted for:

M1: age, country of birth, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence and average driving per week.

M2: age, country of birth, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence and average driving per week, cannabis smoking, alcohol consumption and drug use.

M3: age, country of birth, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence and average driving per week, risk taking score, sensation seeking score and risk perception score.

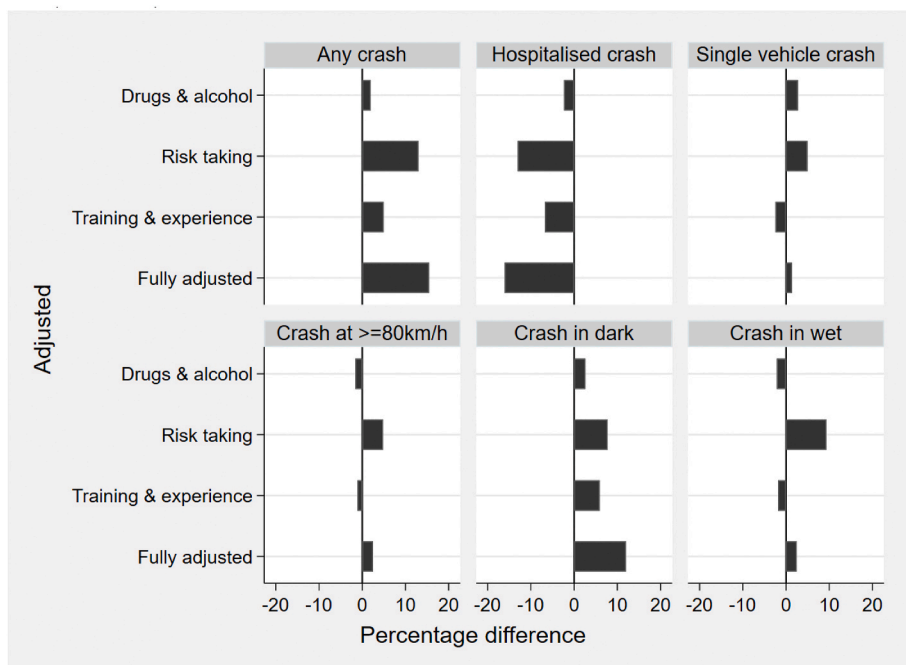
M4: age, country of birth, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence and average driving per week, self-rated driving ability, number of attempts on driver test, crash before study, professional instructor training and time on learner licence.

M5: age, country of birth, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence and average driving per week, risk taking score, sensation seeking score and risk perception score, cannabis smoking, alcohol consumption and drug use, self-rated driving ability, number of attempts on driver test, crash before study, professional instructor training and time on learner licence.

overtaking in a single lane road or speeding, that men are more likely to engage in than women (Jiménez-Mejías et al., 2014). Moreover, men in our study had higher rates of crashes in the dark, which is consistent with Amarasingha and Dissanayake (2014). This association may be explained by sex differences in behavioural tendencies to drive in risky conditions and to take risks in adverse conditions; for example, in extremely adverse environments (e.g. dark or foggy conditions) women drive more cautiously, or may choose not to drive at all and therefore have fewer crashes (Al-Balbissi, 2003). However, the relationship between sex and crashes in adverse conditions is complex, for example, Kelley-Baker and Romano (2010) reported that women were more prone to be involved in manoeuvre and adverse condition crashes than men

when speeding, but women were less likely to speed than men. Clearly, there is much to be understood and unravelling this complexity requires a better appreciation for the intersections between context, sex and/or gender and risky driving behaviours.

Compared with women, a higher proportion of men in the DRIVE cohort reported highest risk taking and sensation seeking scores, as well as poor risk perception and rated their driving ability as much better than other drivers; however, the increased risk of crash involvement among men remained significant even when these factors were controlled. When we consider the minimal impact of risk-taking, sensation seeking, risk perception and self-rated driving ability as predictors of crash risk, there are several possible explanations. Firstly,



**Fig. 2.** Percentage<sup>#</sup> of the confounding-adjusted\* crash RR for sex (men vs. women) explained by each of the risk factors alone and by all risk factors combined. DRIVE cohort, NSW, Australia, 2003–2016.

<sup>#</sup> The percentage excess risk of crash in men compared with women that was due to differences in risk factor levels was estimated by  $100 \left( \frac{[RR_c - RR_A]}{[RR_c - 1]} \right) \%$  where  $RR_c$  and  $RR_A$  are, respectively, the rate ratios for crash comparing men with women adjusted for confounding (c) (Model M1) and after (A) (further) adjustment for each risk factor alone and then for all risk factors combined.

\*adjusted for: age, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence and average driving per week, risk taking score, sensation seeking score and risk perception score, cannabis smoking, alcohol consumption and drug use, self-rated driving ability, number of attempts on driver test, crash before study, professional driver training and time on learner licence.

while men tend to surpass women in engaging in risky driving behaviours, trends suggest that women are increasingly engaging in such behaviours, which has seen a rise in alcohol-related fatal crashes among younger women drivers (Tsai et al., 2010). Thus, in our results, this may reflect the increasing trend of young women engaging in risk taking behaviours and thereby such factors are not substantial contributors to sex differences in crash risk. Alternatively, this may indicate biases in self-report, longitudinal changes in risk behaviour over time and/or other factors, perhaps sex and/or gender-relevant factors, not measured in our study that may be important in explaining the differences in crash involvement between men and women.

One such hypothesis suggests that differences in ‘concern about risk’, is an important determinant of risk-taking behaviour, with men less concerned than women about risk of consequences (Cordellieri et al., 2016). For example, Cordellieri et al. (2016) reported that men and women have similar perception of risk, but men demonstrate less concern about risk of a crash. Taken together, the findings from Cordellieri et al. (2016) and our present results, signal the need for more nuanced investigations of how crash involvement relates to sex and/or gender differences in behaviour, perception and beliefs.

A related hypothesis suggests that the relationship between risky driving and crash may be moderated by sex and/or gender differences in personality factors, including locus of control (Holland et al., 2010) and impulsivity (Navas et al., 2019), as well as aggression (Gulliver & Begg, 2007; Turner & McClure, 2003) and feeling alienated from society, which have been identified as important contributors to crash risk among young men but not young women (Gulliver & Begg, 2007). Moreover, when we consider sex and/or gender differences in underlying motivations for risky driving behaviours, for example speeding, evidence indicates that sensation seeking is an important personality factor in explaining young men’s intention to speed (Cestac et al., 2011). By contrast, Cestac et al. (2011) reported that sensation seeking did not impact women’s speeding behaviour, instead, young women’s self-identity was an important motivator in terms of how they perceived themselves as a “show off” or reckless. Such differences are somewhat reflected in our sample, in which a higher proportion of men reported high levels of sensation seeking tendencies compared to women, and likewise for risk-taking behaviour and perception. However, these relationships require further investigation to understand the role of sex

and/or gender in personality factors, which may have important implications for designing sex and/or gender sensitive interventions and campaigns to address crash risk among young drivers.

Much of the research exploring sex differences in risk factors for road injury centres on behavioural differences in driving exposure. In our sample, a higher proportion of men than women drove 10 or more hours per week, however the difference was minimal (35.4% vs 32.6%). A shortcoming of the present study is our measure of driving exposure, which was self-reported at survey baseline, and thus it is not clear how changes in driving exposure over time may impact sex differences in crash risk in the DRIVE cohort. However, evidence that men and women have different patterns of driving, with men tending to drive greater distances than women, suggests that this may have been an important factor in the crash risk for men in our study (Jiménez-Mejías et al., 2014). This reflects broader differences in mobility patterns, in which women’s travel is more localised than men, with women tending to work closer to home with shorter commutes and more likely to be responsible for household errands and transporting children and older relatives in the course of care giving (Al-Balbissi, 2003; Badstuber, 2019; Gauvin et al., 2020). While this was not recorded in the present study, driving exposure is clearly an important factor in crash risk, yet there is limited insight into how the sex and/or gendered dimensions of driving exposure contribute to crash risk. This could best be addressed through future cohort studies that incorporate naturalistic driving methods, which track driving exposure, driver behaviour and crashes variables, including near misses.

Our results highlight another sex difference; despite men in our cohort being at higher risk of crash overall, women were more likely to be hospitalised as a result of injury sustained in a crash. This difference remained after adjusting for crash risk factors in the analysis. Possible explanations are that women are involved in more severe crashes, are more likely to be hospitalised after a crash and/or are more vulnerable to injury following crash compared with men (Bose et al., 2011; Brumelow & Jermakian, 2021; Carter et al., 2014; Wu et al., 2016).

Higher rate of injury after crash in women compared with men has been explained by biological sex differences in size between males and females, which influences the driver position in the vehicle relative to safety devices such as seat belts and air bags as well other factors such as the proximity to the steering wheel. However, the type of vehicle may

also be important, with a recent study from the United States that also reported higher rates of hospitalised crashes in women compared with men, attributed this to women driving smaller and less safe cars than men (Brumbelow & Jermakian, 2021). This study also pointed to differences in the types of crash, with women being more likely to be struck in side impact crashes. Notably, women's vulnerability to crash-related injury is not mitigated by restraint use, in fact Bose et al. (2011) reported restrained female drivers were more susceptible to injuries and had a higher risk of chest and spine injuries than restrained males in comparable crashes.

While women in our cohort were more likely than men to be hospitalised for contusions, the severity of hospitalised injuries sustained by women were not substantially different from men. This indicates that the higher rate of admission among women is unlikely to reflect increased admissions for less severe injuries. However, a possible confounding factor, not measured in our study are biases in the care system. It is possible that women in our study may have been transported to hospital more than men and/or there may be a lower threshold for admission for women. For instance, women in our cohort were in the age group that pregnancy is likely, and it is possible that women of child-bearing age may have been more likely to be transported, or indeed admitted, to hospital. While such biases in the care system are beyond the scope of the present study, it is important that we consider that sex and/or gender determinants of care may have contributed to this finding. For example, another possible confounding factor is that more men in our cohort may have refused to present to hospital following crash. However, given that our data is only from admitted patients, and therefore reflects more serious injuries, it is unlikely that a substantial proportion of men in our cohort with serious injuries requiring admission to hospital would have refused.

It is likely that other factors, potentially sex and/or gender related factors, that were not measured in our study contributed to the differences observed. To understand possible explanations, we can consider how sex and/or gendered dimensions of driving and road safety may contribute to disparities in both road crash and injury. Firstly, long-held stereotypes that are rooted in binary notions of gender, characterise men as more confident and technically skilled at operating vehicles, while women are characterised as overly cautious and timid drivers (Wachs, 1996). Such stereotypes are bound in historical views, which sought to limit women's equality, and quite literally, "keep women in their place" (Wachs, 1996, p. 106). Historically, from around the 1920's, increased uptake of car ownership and driving among women was important in enabling women to break free from traditional gendered roles of home-based work and nurturing, bringing increased opportunity for mobility and pursuit of employment and education (Wachs, 1996). Yet despite this long history of women as drivers, and the importance of driving mobility in women's equality, it was not until the 1990s that it became widely acknowledged that the design and testing of car safety systems is based on the size and shape of young males (Bose et al., 2011; Carter et al., 2014; Criado-Perez, 2019; Linder & Svensson, 2019). This is an important sex difference in vehicle design and safety testing, which has seen the female body largely ignored in the design, comfort and safety of vehicles.

It is now well established that cars have historically been designed around the 50th percentile male and as a consequence of this females, older people and those who are obese are at greater risk of injury in a crash (Bose et al., 2011; Carter et al., 2014; Linder & Svensson, 2019). Indeed, the predominance of the male body in design and testing of car safety systems, reflects the widely documented under-representation of women's bodies in transport, medical and health research (Badstuber, 2019; Criado-Perez, 2019; Heidari et al., 2016; Law, 1999). In recent years, new simulation and crash test dummies have been developed that aim to better reflect variations in body size and age of the general population (Carlsson et al., 2014; Linder et al., 2013, 2018); the impact of such changes on injury is an important focus for future research. Indeed, to what extent car safety, car design and severity of crash

contribute to the observed differences in hospitalised crashes between men and women needs further exploration. This ideally requires a larger study population. Our study was limited by the comparable small number of crashes resulting in hospital admissions.

### Strengths and limitations

The DRIVE cohort is a large sample of over 20,000 participants with a long follow up of up to 13 years and contains rich information on potential confounders. While the baseline data was collected sixteen years ago, the crash and hospitalisation data are up to and including 2016, therefore the findings reflect the context of positive safety changes that have occurred as a result of technological and infrastructure change. Despite the robustness of this study, the results should be considered in light of the limitations that are inherent to the use of routinely collected data and survey data relying on self-report. Crash data was derived from routinely collected police, hospital and deaths data. Thus, the data did not include crashes that were not reported to police, did not require hospital admission and did not result in deaths. The DRIVE cohort were volunteers, there was potential in self-report data due to social desirability or poor recall (Chapman & Underwood, 2000; Paulhus, 1984). A further consideration relates to a low response rate and potential for selection bias. The overall response rate for DRIVE cohort participants was 15.9%, however the initial response rate was quite low (3%) and this was addressed by reimbursing participants with a cinema ticket. Thereby we cannot rule out that participants who self-selected to join the study were not more inclined toward either more, or less, risky driving behaviour. Despite this, the cohort exhibited wide variation in the exposures of interest at baseline and the population distribution was proportionate with NSW according to the Australian Bureau of Statistics state population statistics in 2006. While cohort studies such as DRIVE provide population estimates of relative associations between risk factors and outcomes, it is important to remember that the DRIVE participants were self-selected and thus the prevalence estimates from the cohort are not representative of the general population.

Beyond the variables included in our modelling, it is possible that other factors that were not measured in this study contribute to the differences observed in crashes between men and women observed in this study. For example, the number of crashes with alcohol involvement were very small in our cohort, and thus we were not able to include this in our modelling to determine sex differences in alcohol-related crashes. While we adjusted for sensation seeking, risk-taking behaviour and risk perception in adolescence, our finding that this did not alter the risk of crash substantially may relate to changes in these measures over time. The E-values (VanderWeele & Ding, 2017) for the key fully adjusted association between sex and crashes ranged from 1.71 to 2.41 for the point estimate, and 1.43–2.83 (Supplementary Table 1). The lower limits of these indicates that our observed associations between sex and crash rate is vulnerable to a confounder that was either moderately strong with common prevalence, in particular the observed association for all crashes and hospitalised crashes. This could be addressed in future studies that repeat these measures at different time points to determine changes with age. Likewise, for driving exposure, our measure for this was taken at baseline and does not account for changes over time, which would be best measured through naturalistic driving studies.

Finally, our approach to examining sex differences in crash risk is a valuable contribution to our understanding of the complexity of differences in crash and injury between men and women, however it is limited to binary notions of sex and is possible that the differences reported in our study may be better understood through the lens of gender. While these are shortcomings of our study, it is indicative of the critical need for a sex and/or gender approach to addressing crash risk and injury and signals the need for more nuanced research that investigates the gendered dimensions of mobility, transport and safety.

## Implications

This research has highlighted substantial gaps in our understanding of the sex and/or gendered dimensions of road crash and injury, which is critical to implementing a safe systems approach and reducing both the overrepresentation of men in crash and the vulnerability of women to injury as a result of crashes. Too often sex and gender are conflated in research, particularly when drawing upon routinely collected administrative data, which tend to be limited to measures of biological sex (Day et al., 2016). Non-binary conceptualisations of gender, and related measures such as caregiving, household composition and distributions of labour, are not represented in our transport data, which limits the utility of this data to inform policy and interventions that address the gendered dimensions of transport and mobility.

Further, we assert that there is a need for greater diversity, and measures of diversity, in samples in road safety research. This includes greater representation from low and middle income countries, who bear a disproportionate burden of road trauma, as well as better reporting of sex and gender (Scott-Parker & Senserrick, 2017). We recommend that future research includes measures of gender and is not limited to biological sex differences, and likewise that a gender lens is applied to transport policy, safety and design.

## Conclusion

In the DRIVE cohort of young drivers with a 13-year follow-up period, there were sex differences observed in crash and crash-related injury. Men had higher rates than women for all crash types, except crashes that resulted in hospitalisation. Our findings indicate that men's higher risk of crash as a young driver persists as men get older and gain more driving experience. Overall, our findings point to complexity in the sex and/or gendered dimensions of driving and crash, signalling the need for a life-course approach to understanding the factors that shape risk across a person's life to ensure that interventions can be targeted accordingly.

## Author statement

Patricia Cullen: Conceptualization; Methodology; Investigation; Writing - Original Draft; Writing - Review & Editing; Project administration.

Holger Moeller: Conceptualization; Methodology; Formal analysis; Writing - Original Draft; Writing - Review & Editing.

Mark Woodward: Conceptualization; Methodology; Writing - Review & Editing.

Teresa Senserrick: Methodology; Writing - Review & Editing; Funding acquisition.

Soufiane Boufous: Methodology; Writing - Review & Editing; Funding acquisition.

Kris Rogers: Methodology; Formal analysis; Writing - Review & Editing; Supervision.

Julie Brown: Writing - Review & Editing.

Rebecca Ivers: Conceptualization; Methodology; Investigation; Writing - Review & Editing; Supervision; Funding acquisition.

## Ethics statement

Ethics approval and consent to participate: This study was approved by the Aboriginal Health and Medical Research Council Ethics Committee (Reference: 1338/17) and the NSW Population & Health Services Research Ethics Committee (Reference: 2016/04/637).

## Declarations of competing interest

None.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ssmph.2021.100816>.

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