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Driving offences and risk of subsequent crash in novice drivers: the DRIVE cohort study 12-year follow-up

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ABSTRACT

Background Penalties are a key component to improve road user safety, but previous studies suggested that they might not be successful in reducing crashing in offending drivers. However, these studies were not able to consider important crash risk factors in the analysis that might confound the results. Using data from a large prospective cohort study of young drivers in New South Wales, Australia, we explored if novice drivers with driving offences have a higher rates of car crash and if these differences are explained by established crash risk factors.

Methods We used data from a 2003/2004 Australian survey of young drivers, linked to police reported offence and crash data, hospital data and deaths data up to 2016. We used Poisson regression models adjusted for confounders to estimate the association between driving offences during 2003–2006 with car crash during 2007–2016.

Results The study cohort comprised 20 781 young drivers of whom 7860 drivers (37.8%) had at least one driving offence and 2487 (12.0%) were involved in at least one crash. After adjusting for confounders in the regression model, drivers with three or more driving offences had 2.25 (95% CI 1.98 to 2.57), 2.87 (95% CI 1.60 to 5.17) and 3.28 (95% CI 2.28 to 4.72) times higher rates of any crash, crashes that resulted in hospital admission or death and single vehicle crashes compared with drivers with no driving offences.

Conclusion Measures that successfully mitigate the underlying risk factors for both, crashes and offences, have the potential to improve road safety.

BACKGROUND

Road transport crashes are a leading cause of injury and deaths worldwide.¹ In Australia, 1195 people died and 39 330 were hospitalised due to road transport crashes in 2019.² Young drivers aged 17–25 years are disproportionately affected, attributing 25% of crashes resulting in serious injury even though they only make up around 15% of the Australian population of driving age.³

Reducing road transport crashes is an international policy priority^{4–7} and Australia, like many other countries, has adopted a safe systems approach comprising of four target areas: safe roads, safe speeds, safe vehicles and safe road users.^{4 5} Law enforcement and penalties combined with social marketing and education campaigns are key components to improve road user safety.

Penalty systems are based on deterrence theory that assumes that crime is deterred by the threat of punishment.⁸ Studies on the effectiveness of penalty systems to increase road safety show that they can be successful in reducing dangerous driving behaviours, such as drink driving^{9 10} and associated road transport crashes.^{11–14} However, individual-level studies show that drivers who incur offences are also at increased risk of car crash.^{15–23} It has therefore been suggested that driving offences are an indicator of risky driving behaviours^{15 16} that, in turn, are associated with an increased risk of crash.^{24–26}

Previous studies reported crash and traffic offence rates in novice drivers,^{27–29} but few studies have specifically looked at driving offences and subsequent risk of crash in young novice drivers. A cohort study of young drivers from Queensland, Australia, reported 31% and 41% higher rate of crash resulting in injury or deaths for drivers with at least one drink driving or speeding offence, respectively, compared with drivers with no such offence.²⁰ This is in line with findings from a study from Western Australia, which found that both infringements and convictions were predictive of first year drivers' involvement in a subsequent crash and that infringements alone were predictive of first year drivers' involvement in a subsequent serious injury crash.²¹ Similarly, another study from Western Australia showed an increased risk of drink driving related crashes in novice drivers who had a previous drink driving offence that resulted in a road crash²² and a study of young drivers from Michigan in the USA reported drivers with an offence in the previous year to have a 40% increased risk of crash compared with drivers with no offences.²³ Similar findings have been reported in cohort studies of drivers of all ages. A study from Queensland, Australia, showed that drivers had up to three times higher risk of crash in the month following an infringement, relative to a comparable driving period 12 months prior.¹⁷ The authors concluded that penalties might indicate periods of risky driving and might not have an immediate effect on reducing dangerous driving behaviours and the risk of crash.¹⁷ Similarly, cohort studies from Israel and Australia found that drivers with previous traffic offences were at increased risk of crash.^{15 16} However, these previous studies either did not consider confounders in the analysis^{20 21} or were limited in the amount of confounders considered.

The young driver cohort (DRIVE) study is a large prospective cohort study of more than 20 000 young drivers in New South Wales (NSW), Australia, which has recently been relinked with police reported crash and hospital data resulting in up to 13 years of follow-up.³⁰ The DRIVE study collected information on a large number of crash risk factors, allowing to explore the following research questions: do young novice drivers with driving offences during their first years of driving have a higher risk of car crash up to 13 years after they first started driving compared with drivers with no offences? Does this vary by type of driving offence and type of crash? Are differences in risk of crash between drivers with and without offences explained by established crash risk factors?

METHODS

Study design

The study was a prospective cohort study.

Setting

NSW is Australia's most populous state with 7.5 million residents³ and 4.28 million registered passenger vehicles, the most of any state in Australia.³¹

Data sources

We used data from the DRIVE study, a 2003/2004 survey of 20 822 young drivers in NSW Australia.³⁰ Drivers were eligible to participate if they were 17–24 years old and held their first-stage NSW provisional motor vehicle (car) driver's licence. The DRIVE study collected information on driver's demographics, driving exposure, driver's experience and training and known and hypothesised crash risk factors (table 1).^{24,30} Data collection and the study cohort have been described in detail elsewhere.³⁰

The survey data were linked with data from state and federal government authorities: offence data from Transport for NSW, police recorded crash data from the NSW Centre for Road Safety, hospital data from the NSW Admitted Patient Data Collection (APDC), death data from the NSW Registry of Births Deaths and Marriages (RBDM) and cause of death data from the Australian Bureau of Statistics (ABS). Police reported crashes, hospital and death data were available up to 2016 and offence and sanctioning data from study entry in 2003/2004 until 31 December 2006.

The offence data contain information on all recordable offences, by type of driving offence and driving sanctions issued. The NSW Centre for Road Safety CrashLink system provides information on all persons injured or killed due to road crashes that occur on NSW public roads. The data provide, among other, information on the severity and circumstances of the crash. The APDC 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.³² The NSW RBDM contains information on all deaths in NSW. The ABS cause of death data includes information derived from the death certificate or coronial report on the cause of deaths.

The NSW Centre for Health Record Linkage (www.cherel.org.au) performed probabilistic linkage of the data sets and supplied deidentified data sets for analysis. For the crash, offence, hospital and death data, a master linkage key of identifying fields was derived using probabilistic record linkage methods and Choice-Maker software,³³ which uses 'blocking' and 'scoring' to identify

definite and possible matches. Mortality data were linked via deterministic linkage.

Variables in the analysis

The risk factors under investigation were any driving offence or a driving offence for reckless driving, speeding, low-level speeding (exceeding speed limit by not more than 15 km/hour) or any other driving offence while driving a car by participants from study entry during 2003/2004 until 31 December 2006.

The study outcome measures were total number of crashes (police recorded crash, crash-related hospitalisation or death of the driver), crash-related hospitalisations or deaths of the driver and single vehicle crashes during follow-up from 1 January 2007 to 31 December 2016. Drivers who were sanctioned from driving were followed up after the end of the sanctioning period. Only crashes related to vehicles that the study participants could legally drive with an 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 and .5) were included in the study. 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 1 day of a record in the police reported crash data were considered the same crash.

Potential confounders were identified from the survey data. These were measures of driver demographic characteristics (age, gender, geographical remoteness and socioeconomic status of area of residence and country of birth), mental health and drug and alcohol use (self-harm, 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 the start of follow-up not related to driving offences included in the study), driving behaviour and attitude (risk taking behaviour, risk perception and sensation seeking) and driving exposure (average weekly driving) (table 1, online supplemental table 1).³⁰ The selection of potential confounders for inclusion in the multivariable regression was based on evidence from previous analyses of the DRIVE data and the international literature,^{24 34–37} a detailed description of these variables and their data sources can be found in the online supplemental table 1.

We classified geographical remoteness of residence using the accessibility/remoteness index of Australia,³⁸ and derived socioeconomic status (SES) from the ABS 2001 area level index of education and occupation,³⁹ which was divided into NSW population quartile groups. We linked remoteness and SES information to the survey data by matching postal area.

Statistical analysis

Although completeness of recording of survey variables used in the multivariable regression analysis was high (93%–100%), the joint percentage of missing data across analysis variables was 15%. For the regression analysis, missing values in the survey data were imputed using chained equations in Stata with 30 imputation cycles.³⁴ The imputation model was assessed by plotting the imputed values against the non-missing data for each imputation cycle using the Stata user written package *midplots*³⁵ and through numerical checks using descriptive statistics comparing the imputed with the non-missing data. Recording of outcome and the exposure (driving offence) data was complete, because this was derived from population level registry data.

Table 1 Cohort characteristics by number of driving related offences*

	None (n=12 921)		One (n=4644)		Two (n=1825)		Three or more (n=1391)		Total (n=20 871)					
	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number	Number				
Demographics														
Gender	Female	7976 (61.7)	2295 (49.4)	707 (38.7)	371 (26.7)	11 349	Male	4945 (38.3)	2349 (50.6)	1118 (61.3)	1020 (73.3)	9432		
Age (years)	17	5997 (46.4)	2416 (52.0)	953 (52.2)	752 (54.1)	10 118	18–19	4880 (37.8)	1684 (36.3)	671 (36.8)	493 (35.4)	7728		
	20–25	2044 (15.8)	544 (11.7)	201 (11.0)	146 (10.5)	2935	Australia/New Zealand	10 960 (86.5)	4049 (88.5)	1634 (90.8)	1218 (89.0)	17 861		
Country of birth	Other	1706 (13.5)	527 (11.5)	166 (9.2)	151 (11.0)	2550	Least disadvantaged	3448 (26.7)	1053 (22.7)	375 (20.5)	255 (18.3)	5131		
Area-level SES	Second quartile	3198 (24.8)	1154 (24.8)	455 (24.9)	326 (23.4)	5133	Third quartile	3247 (25.1)	1266 (27.3)	505 (27.7)	429 (30.8)	5447		
	Most disadvantaged	3028 (23.4)	1171 (25.2)	490 (26.8)	381 (27.4)	5070	Metro	9668 (74.8)	3414 (73.5)	1349 (73.9)	1021 (73.4)	15 452		
Remoteness	Inner regional	2672 (20.7)	1012 (21.8)	385 (21.1)	319 (22.9)	4388	Outer regional/remote	581 (4.5)	218 (4.7)	91 (5.0)	51 (3.7)	941		
Driving and experience and training	Attempts on driver test	1	8486 (65.9)	3011 (65.0)	1160 (63.6)	815 (58.8)	13 472	2	3028 (23.5)	1123 (24.3)	441 (24.2)	364 (26.3)	4956	
	3 or more	1360 (10.6)	496 (10.7)	222 (12.2)	207 (14.9)	2285	Time on learners-licence	<1 year	4608 (35.8)	1880 (40.6)	786 (43.2)	652 (47.1)	7926	
	1–1.5 years	4615 (35.9)	1659 (35.9)	657 (36.1)	473 (34.2)	7404	>1.5 years	3646 (28.3)	1086 (23.5)	378 (20.8)	260 (18.8)	5370		
	Crash before study	Yes	46 (0.4)	292 (6.3)	151 (8.3)	125 (9.0)	614	Self-rated driving ability compared with other drivers	Much better	2041 (16.3)	913 (20.4)	418 (23.8)	356 (27.1)	3728
		0	2096 (16.2)	1717 (17.6)	401 (22.0)	340 (24.4)	3654	Better	5459 (43.6)	1975 (44.1)	755 (43.0)	569 (43.3)	8758	
		1–4	1916 (15.6)	396 (30.1)	563 (30.8)	434 (31.2)	5909	Same	4788 (38.2)	1529 (34.2)	554 (31.6)	371 (28.2)	7242	
		5–8	2679 (20.7)	1110 (21.8)	359 (19.7)	242 (17.4)	4291	Worse or much worse	239 (1.9)	57 (1.3)	28 (1.6)	18 (1.4)	342	
		9+	4630 (35.8)	1420 (30.6)	502 (27.5)	375 (27.0)	6927	Lessons with professional driving instructor (hours)	0	2096 (16.2)	1717 (17.6)	401 (22.0)	340 (24.4)	3654
								1	1916 (15.6)	396 (30.1)	563 (30.8)	434 (31.2)	5909	
								2	2679 (20.7)	1110 (21.8)	359 (19.7)	242 (17.4)	4291	
								3	4630 (35.8)	1420 (30.6)	502 (27.5)	375 (27.0)	6927	

Continued

Table 1 Continued

	None (n=12 921)		One (n=4644)		Two (n=1825)		Three or more (n=1391)		Total (n=20 871)	
	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number	Number
Drug and alcohol and mental health	Marijuana smoking in last 12 months									
	Never	11 123 (88.8)	3785 (84.8)	1404 (80.3)	951 (72.3)	17 263				
	Once a month or less	1104 (8.8)	511 (11.4)	248 (14.2)	228 (17.3)	2091				
	2–4 times a month	175 (1.4)	104 (2.3)	50 (2.9)	71 (5.4)	400				
	2–3 or 4+ per week	119 (1.0)	66 (1.5)	46 (2.6)	66 (5.0)	297				
	Use of other drugs in last 12 months									
	Never	11 830 (94.6)	4113 (92.3)	1579 (90.5)	1127 (86.1)	18 649				
	Once a month or less	528 (4.2)	262 (5.9)	120 (6.9)	121 (9.2)	1031				
	2–4 times a month	101 (0.8)	56 (1.3)	32 (1.8)	47 (3.6)	236				
	2–3 or 4+ per week	40 (0.3)	27 (0.6)	14 (0.8)	14 (1.1)	95				
	Alcohol audit summary score									
	0–6	11 243 (89.6)	3791 (84.7)	1392 (79.3)	1012 (76.7)	17 438				
	>6	1300 (10.4)	686 (15.3)	363 (20.7)	307 (23.3)	2656				
	Self-harm									
	No	11 386 (93.3)	3963 (91.0)	1513 (89.6)	1107 (87.3)	17 969				
	Yes	812 (6.7)	391 (9.0)	176 (10.4)	161 (12.7)	1540				
	Risk taking score									
	Low	5123 (41.5)	1189 (27.0)	344 (20.0)	194 (15.1)	6850				
	Medium	4088 (33.1)	1498 (34.0)	533 (30.9)	332 (25.8)	6451				
	High	3126 (25.3)	1719 (39.0)	846 (49.1)	760 (59.1)	6451				
	Risk perception score									
	Low	4275 (34.8)	1251 (28.6)	424 (24.7)	259 (20.4)	6209				
	Medium	3954 (32.2)	1376 (31.5)	484 (28.2)	333 (26.2)	6147				
	High	4058 (33.0)	1743 (39.9)	806 (47.0)	680 (53.5)	7287				
	Sensation seeking score									
	Low	4521 (36.8)	1163 (26.6)	337 (19.7)	236 (18.5)	6257				
	Medium	4048 (33.0)	1465 (33.5)	528 (30.9)	345 (27.1)	6386				
	High	3710 (30.2)	1749 (40.0)	844 (49.4)	692 (54.4)	6995				
Driving exposure	Average weekly driving (hours)	7.5 (12.7)	9.6 (13.2)	10.8 (11.6)	14.6 (24.7)	8.7 (13.9)				

* Offences from joining DRIVE study in 2003/2004 until end of 2006, missing values not shown. SES, socioeconomic status.

Table 2 Number of crashes during follow-up (2007–2016) by driving offence type*

		Any crash			Hospitalised crash or deaths		Single vehicle crash		Total
		None	One	Two or more	None	One or more	None	One or more	
		Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	
Any offence	None	11 646 (63.7)	1166 (52.2)	109 (43.1)	12 860 (62.3)	61 (47.3)	12 809 (62.4)	112 (42.6)	12 921
	One	4021 (22.0)	556 (24.9)	67 (26.5)	4610 (22.3)	34 (26.4)	4576 (22.3)	68 (25.9)	4644
	Two	1547 (8.5)	247 (11.1)	31 (12.3)	1809 (8.8)	16 (12.4)	1788 (8.7)	37 (14.1)	1825
	Three or more	1080 (5.9)	265 (11.9)	46 (18.2)	1373 (6.7)	18 (14.0)	1345 (6.6)	46 (17.5)	1391
Reckless driving	None	17 418 (95.2)	2049 (91.7)	227 (89.7)	19 585 (94.8)	109 (84.5)	19 458 (94.8)	236 (89.7)	19 694
	One or more	876 (4.8)	185 (8.3)	26 (10.3)	1067 (5.2)	20 (15.5)	1060 (5.2)	27 (10.3)	1087
Speeding	None	14 005 (76.6)	1524 (68.2)	155 (61.3)	15 595 (75.5)	89 (69.0)	15 523 (75.7)	161 (61.2)	15 684
	One	3254 (17.8)	490 (21.9)	62 (24.5)	3779 (18.3)	27 (20.9)	3740 (18.2)	66 (25.1)	3806
	Two or more	1035 (5.7)	220 (9.9)	36 (14.2)	1278 (6.2)	13 (10.1)	1255 (6.1)	36 (13.7)	1291
Low speeding offence	None	16 201 (88.6)	1933 (86.5)	212 (83.8)	18 238 (88.3)	108 (83.7)	18 123 (88.3)	223 (84.8)	18 346
	One or more	2093 (11.4)	301 (13.5)	41 (16.2)	2414 (11.7)	21 (16.3)	2395 (11.7)	40 (15.2)	2435
Other offences	None	14 990 (81.9)	1654 (74.0)	178 (70.4)	16 732 (81.0)	90 (69.8)	16 649 (81.1)	173 (65.8)	16 822
	One or more	3304 (18.1)	580 (26.0)	75 (29.6)	3920 (19.0)	39 (30.2)	3869 (18.9)	90 (34.2)	3959
	Total	18 294 (100.0)	2234 (100.0)	253 (100.0)	20 652 (100.0)	129 (100.0)	20 518 (100.0)	263 (100.0)	20 781

*Offences from joining DRIVE study in 2003/2004 until end of 2006.

We examined time to first crash during follow-up for different categories of driving offences using cumulative incidence curves. We analysed the association between the different crash outcomes and risk-taking behaviour in univariate and multivariable Poisson regression models with robust variance estimates.³⁶ Count of crash events was the numerator and number of study participants the denominator in the models.

We included time between start (1 January 2007 or the end of sanctioning period) and end of follow-up (31 December 2016) as an offset variable in the regression models to account for different lengths of exposure of drivers who were banned from driving. We censored participants who died during follow-up at the date of deaths. Participants were followed from 1 January 2007 to 31 December 2016.

The influence of known crash risk factors on differences in crash between drivers with and without driving offences was investigated by adding measures of drug use and self-harm (model 2), risk taking behaviour (model 3), driver training and experience (model 4) separately and all of these measures combined (model 5) to the regression model adjusted for driver demographics and driving exposure (model 1) (online supplemental table 2).

All statistical analyses were carried out using Stata V.15.

RESULTS

The final study cohort comprised 20 781 young drivers (54.6% women). Records of 25 participants who died before follow-up

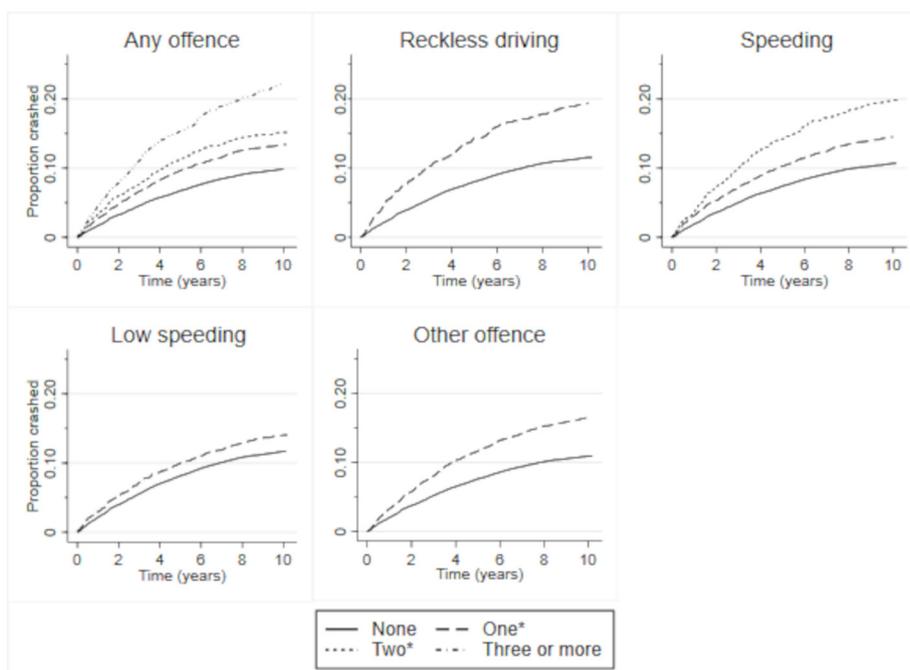


Figure 1 Time to first crash (2007–2016) by prior driving offence#. #Offences from joining DRIVE study in 2003/2004 until end of 2006. *One or more/two or more for offences with less than three categories

Table 3 Rate ratios* of any crash, hospitalised crash or death and single vehicle crash during 2007–2016 by type of driving offence 2003–2006

			M1 demographics and driving exposure	M5 fully adjusted
			RR (95% CI)	RR (95% CI)
Any crash	Any offence	One	1.34 (1.22 to 1.48)	1.35 (1.22 to 1.49)
		Two	1.48 (1.30 to 1.69)	1.50 (1.31 to 1.71)
		Three or more	2.22 (1.96 to 2.52)	2.25 (1.98 to 2.57)
	Reckless driving†	One or more	1.35 (1.18 to 1.56)	1.35 (1.17 to 1.56)
		Speeding†	One	1.24 (1.12 to 1.36)
	Low speeding offence†	Two or more	1.57 (1.37 to 1.81)	1.59 (1.38 to 1.83)
		One or more	1.06 (0.95 to 1.19)	1.07 (0.95 to 1.20)
	Other offences†	One or more	1.42 (1.27 to 1.60)	1.43 (1.28 to 1.61)
	Hospitalised crash or death	Any offence	One	1.52 (0.99 to 2.34)
Two			1.75 (0.98 to 3.11)	1.76 (0.98 to 3.18)
Three or more			2.83 (1.58 to 5.05)	2.87 (1.60 to 5.17)
Reckless driving†		One or more	3.00 (1.81 to 4.95)	3.00 (1.83 to 4.92)
		Speeding†	One	1.07 (0.67 to 1.72)
Low speeding offence†		Two or more	1.43 (0.75 to 2.71)	1.47 (0.77 to 2.79)
		One or more	1.34 (0.82 to 2.18)	1.33 (0.82 to 2.16)
Other offences†		One or more	1.71 (1.01 to 2.89)	1.77 (1.06 to 2.96)
Single vehicle crash		Any offence	One	1.59 (1.17 to 2.17)
	Two		1.94 (1.32 to 2.86)	2.03 (1.36 to 3.01)
	Three or more		3.16 (2.22 to 4.52)	3.28 (2.28 to 4.72)
	Reckless driving†	One or more	1.32 (0.88 to 1.99)	1.32 (0.88 to 1.99)
		Speeding†	One	1.39 (1.03 to 1.86)
	Low speeding offence†	Two or more	1.86 (1.26 to 2.74)	1.92 (1.29 to 2.85)
		One or more	1.04 (0.74 to 1.46)	1.05 (0.75 to 1.48)
	Other offences†	One or more	1.90 (1.37 to 2.64)	1.90 (1.36 to 2.66)

M1: age, sex, socioeconomic status of area of residence (Socio-economic Indexes for Areas (SEIFA)), remoteness of area of residence and average driving per week.
M5: age, sex, socioeconomic status of area of residence (SEIFA), remoteness of area of residence, average driving per week, cannabis smoking, alcohol consumption, drug use and self-harm, risk perception score, risky driving score, sensation seeking score, self-rated driving ability, number of attempts on driver test, crash before start of follow-up not related to driving offence, lessons with professional driving instructor and time on learner licence.
*Model adjusted for.
†Adjusted for all other driving offences (calculated as number of any offence minus offence under investigation).

and 16 duplicate records were excluded. Most participants were 17–19 years old (85.9%) and lived in metropolitan areas (74.4%) at the time of joining the study.

A total of 7860 drivers (37.8%) sustained at least one driving offence (table 1). Speeding was the most common type of driving offence (n=5097, 24.5%), and 2435 drivers (11.7%) were recorded as having at least one low speeding offence. Reckless driving was the second most common offence type investigated in this study (n=1087, 5.2%), and not displaying mandatory provisional licence plates (n=2131, 90.2%) was the most common type of offence among other offences (n=2363, 11.4%) (online supplemental table 3–6).

Compared with drivers with no driving offences a higher proportion of drivers with one or more offences reported high risk taking and sensation seeking behaviours and more frequent cannabis smoking and alcohol consumption (table 1). During the study period 2487 (12.0%) participants were involved in at least one car crash, of these, 129 (0.6%) were hospitalised for crash related injuries, 5 died in a car crash and 263 (1.3%) had a single vehicle crash (table 2).

For all types of driving offences, a higher proportion of drivers with a registered offence crashed during follow-up (figure 1). For any offence, the rate of crash increased by number of driving offences, with 13.4%, 15.2% and 22.4% of drivers with one, two and three or more offences, respectively, having been involved in at least one crash by the end of follow-up. Of those

with one or more reckless driving offences, 19.4% had crashed at the end of follow-up, compared with 11.5% of drivers with no such offence.

After adjusting for confounding in the multivariable regression analysis (table 3), we observed an increased rate of crash for drivers with any driving offence for all crash outcomes. The rate of crash increased with the number of driving offences for all three crash outcomes investigated. Drivers with three or more driving offences had 2.25 (95% CI 1.98 to 2.57), 2.87 (95% CI 1.60 to 5.17) and 3.28 (95% CI 2.28 to 4.72) times higher rates of any crash, crashes that resulted in hospital admission or death and single vehicle crashes compared with drivers with no driving offences (figure 2). Drivers with one or more reckless driving offences had 1.35 (95% CI 1.17 to 1.56), 3.00 (95% CI 1.83 to 4.92) and 1.32 (95% CI 0.88 to 1.99) times higher rates of any crash, crashes that resulted in hospital admission or death and single vehicle crashes, respectively, compared with drivers with no reckless driving offences. Drivers with one or more low speeding offences had no increased rate of crash. Entering potential risk factors for crash separately to the model showed that these only had little effect on the differences in crash rates between drivers with and without driving offences (online supplemental table 7).

DISCUSSION

We showed that drivers with police reported offences during the first 3 years of driving had increased rates of crash up to 9

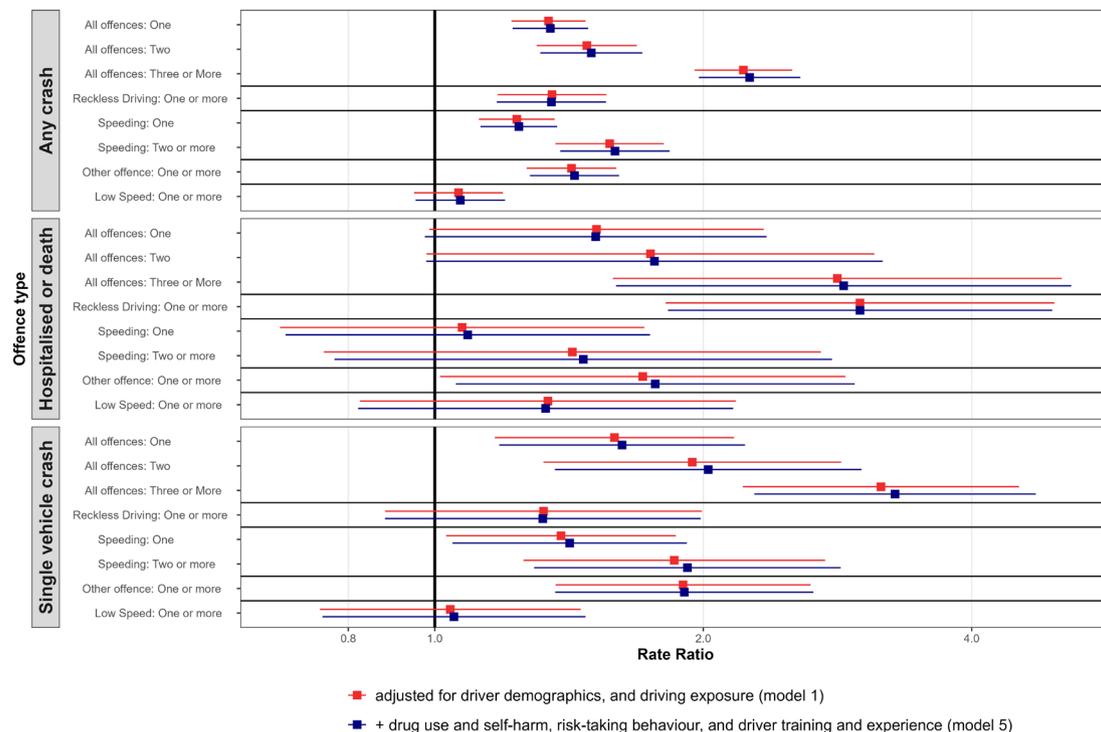


Figure 2 Rate ratios[#] of any crash, hospitalised crash or death and single vehicle crash during 2007–2016 by type of driving offence 2003–2006. #Model adjusted for: M1: age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence and average driving per week. M5: age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence, average driving per week, cannabis smoking, alcohol consumption, drug use and self-harm, risk perception score, risky driving score, sensation seeking score, self-rated driving ability, number of attempts on driver test, crash before start of follow up not related to driving offence, lessons with professional driving instructor and time on learner licence.

years later compared with those with no driving offences. The rate of crash increased with higher number of driving offences. Adjusting for established crash risk factors only had a small effect on the differences in crash between drivers with and without offences.

Our findings add to and expand on those of previous studies that also showed an increased risk of crash in drivers with previous driving offences.^{15 16} Similar to our findings of an increased risk of crash in drivers with more driving offences, previous studies from Australia²⁰ and the USA²³ reported a 40% increased risk of crash in young drivers with driving offences and a cohort study from Israel showed a 65% increased risk of severe and fatal crash per driving ticket per year.¹⁶ In comparison, a study from Western Australia reported 3%–13% increased odds of traffic offence for drivers that required hospital admission for crash-related injuries.¹⁵ The comparably smaller risk reported in this study can at least in part be explained by differences in study design. The Western Australian study only included subjects hospitalised for crash and retrospectively assessed if these had prior driving offences. In comparison, our study prospectively measured if drivers with a driving offence were involved in a car crash.

Another study from Queensland, Australia, reported an increased risk of crash in the month after a driving-related offence relative to a comparable driving period 12 months prior.¹⁷ The risk of crash decreased with increasing time after the offence and the authors concluded that offences might indicate periods of risky driving that in turn might be associated with an increased risk of being involved in a crash. Our results are not directly comparable due to differences in study design. The Queensland study used a case cross-over design thereby comparing driving

periods and risk of crash in the same driver in the months after a driving offence compared with a similar time period 12 months prior. In comparison, we followed drivers for up to 9 years after a driving offence but could not ascertain the temporal relationship between further offence and crash as our offence data were limited up to 2006.

Although penalty systems have been shown to have a deterrent effect at population level,^{9–14} our results suggest that they might not be successful in reducing the risk of crash in some of the drivers who already offended, in particular in those with repeat offences. Previous studies suggested that the relationship between driving offences and crash might be explained by higher risk-taking behaviours in those with driving offences.^{15 16} In our study, drivers with offences reported higher levels of risky driving, sensation seeking behaviours and drug and alcohol use compared with those with no driving offences, but adjusting for these in the analysis did not explain differences in crash. Possible explanations could be that reported risky driving and sensation-seeking behaviours differ from actual driving behaviour; the instruments used to measure these behaviours do not accurately reflect these or that driving offences are an indicator for other driver characteristics that were not accounted for in the study. For example, a previous study investigating sensation-seeking behaviour and riding style in a moped simulator showed that high thrill and adventure seekers performed worse only if they also were bad decision makers.³⁷ To what extent decision making and other factors contribute to crash in those with driving offences needs further investigation. This could be explored in naturalistic driving studies that collect information on driver behaviour linked with offence and crash data.

Based on their findings that offences mark episodes of risky driving, the authors of the Queensland study suggested that a licence suspension version of ‘flash incarceration’ may yield safety benefits.¹⁷ Although such measures might have an immediate effect, our findings showed that measures targeting the underlying reason of repeat offending and identification of factors contributing to crash in this group of drivers are needed to achieve long-term benefits. Brief interventions focusing on personal psychological risk factors integrated into driver training programmes have been shown to be effective in reducing speed-related traffic violations.⁴⁰ Moreover, evidence from the effectiveness of programmes targeting drink driving showed that holistic early intervention programmes combining deterrence and addressing the underlying problem behaviours might be successful in reducing offending and associated car crashes.⁴¹ In NSW, intervention programmes are currently only targeted at drivers with drink driving offences. Additional programmes aimed at drivers with other driving offences, in particular repeat driving offences, have the potential to further reduce repeat offences and crashes.

However, research on socioeconomic status and driving offences showed that drivers from low socioeconomic background are disproportionately affected.⁴² Similar findings have been reported for the relationship of socioeconomic status and crash.^{43 44} These findings suggest that road transport injury prevention also needs to address the underlying causes of social inequalities to reduce driving offences and crash.

Strength and limitations

The strengths of this study are its large sample size of over 20 000 participants, the rich information on potential confounders and the long follow-up.

Some of the limitations are inherent to the use of routinely collected data and survey data relying on self-report. Crash data were derived from NSW routinely collected police, hospital and deaths data. Crashes that were not reported to police, did not require hospital admission and did not result in deaths or occurred outside of NSW were not covered in the analysis. Participants in the DRIVE study were volunteers; as such, the cohort was not a representative sample of the general population. Like other large cohort studies, the DRIVE study can only provide generalisable estimates of the relative associations

between risk factors and outcome,^{45 46} but not absolute numbers or incidence rates. Another limitation was potential bias in self-reported data, which could, for example, occur from recall bias or social desirable responding to interview questions.^{47 48}

Information on driving offences was only available for the first 3 years of driving as such we could not ascertain if drivers with subsequent crashes had further driving offences and if these were at the time of the crash. Moreover, measures of potential confounders were based on information from the baseline interview, and we were not able to adjust for changes during follow-up.

CONCLUSION

Repeat driving offenders have a substantially higher risk of crash compared with drivers with no offences. Measures that successfully mitigate the underlying risk factors for both, crashes and offences, have the potential to improve road-safety.

Correction notice This article has been corrected since it was first published. The open access licence has been updated to CC BY.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by Australian Health and Medical Research Council Ethics Committee ID:HREC/16/CIPH/9. Participants gave informed consent to participate in the study before taking part.

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What is already known on the subject

- ⇒ Young novice drivers are disproportionately affected by road transport crashes.
- ⇒ Penalties are key component to improve road user safety.
- ⇒ Drivers who incur offences are at increased risk of car crash.

What this study adds

- ⇒ Drivers with police reported offences are at increased risk of crash up to 9 years later.
- ⇒ The risk of crash increases with higher number of driving offences.
- ⇒ Drivers with reckless driving offences have highest rates of hospitalised crashes.
- ⇒ Adjusting for established crash risk factors does not explain higher crash rates.

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Supplementary data

Driving offences and risk of subsequent crash in novice drivers. The DRIVE cohort study 12 year follow up.

Table supplement 1: Variables in the analysis, data source, categories and reference. The DRIVE study, NSW, Australia, June 2003–December 2004.

Variable	Source	Category / unit in the analysis	Reference
Age	Baseline questionnaire	Single year derived from date of birth	
Sex	Baseline questionnaire	Male / female	
Country of birth	Baseline questionnaire	Australia & New Zealand Other	
Remoteness	Accessibility/Remoteness index of Australia, linked to study data by postcode of area of residence	Metro Inner regional Outer regional / remote	Trewin D. Australian Standard Geographical Classification (ASGC). ABS Catalogue No 12160: Australian Bureau of Statistics; 2004.
Socioeconomic status	Australian Bureau of Statistics 2001 area level index of education and occupation linked to study data by postcode of area of residence	Least disadvantaged 2nd quartile 3rd quartile Most disadvantaged	Trewin D. Socio-Economic Indexes for Areas. Census of population and housing. Canberra, ACT: Australian Bureau of Statistics; 2001.
Attempts on driver test	NSW driver licencing data linked with survey data	Number of attempts	
Crash before study	Transport for NSW crash data linked with survey data	Yes / No	
Time on learners' licence	NSW driver licencing data linked with survey data	< 1 year 1-1.5 years > 1.5 years	
Self-rated driving ability compared to other drivers	Baseline questionnaire	Five point Likert scale <ul style="list-style-type: none"> • Much better • Better • Same • Worse • Much worse 	
Lessons with professional driving instructor (hours)	Baseline questionnaire	Number of lessons with professional driving instructor	Adapted from the Western Australian Young Driver Cohort Study and the University of Otago Young Driver Pilot Study. Stevenson MR, Palamara P. Behavioural factors as predictors of motor vehicle crashes: differentials between young urban and rural drivers, Aust N Z J Public Health 2001;25:245–9. Begg D, Brookland R, Hope J, et al. New Zealand drivers study: developing a methodology for conducting a follow-up study of newly licensed drivers. J Safety Res 2003;34:329–36.
Marijuana smoking in last 12 months	Baseline questionnaire	<ul style="list-style-type: none"> • Never • Once a month or less • 2-4 times a month • 2-3 times per week • 4plus per week 	Centers for Disease Control and Prevention. Methodology of the youth risk behaviour surveillance system, Morb Mortal Wkly Rep, 2004;53:1–14

Variable	Source	Category / unit in the analysis	Reference
Use of other drugs in last 12 months	Baseline questionnaire	<ul style="list-style-type: none"> • Never • Once a month or less • 2-4 times a month • 2-3 times per week • 4plus per week 	Centers for Disease Control and Prevention. Methodology of the youth risk behaviour surveillance system, <i>Morb Mortal Wkly Rep</i> , 2004;53:1–14.
Alcohol audit summary score	Baseline questionnaire	<p>AUDIT-C, Alcohol Use Disorders Identification Test Consumption sub-scale. Summary score derived from the three alcohol audit questions grouped into 0-6 and >6.</p> <p>1. How often do you have a drink containing alcohol?</p> <ul style="list-style-type: none"> • Never • Once a month or less • 2-4 times a month • 2-3 times a week • 4 times a week or more <p>2. How many drinks of alcohol would you have on a typical day when you are drinking?</p> <ul style="list-style-type: none"> • 1 or 2 • 3 or 4 • 5 or 6 • 7, 8 or 9 • 10 or more <p>3. How often would you have six or more drinks on one occasion?</p> <ul style="list-style-type: none"> • Never • Once a month or less • 2-4 times a month • 2-3 times a week • 4 times a week or more 	<p>Babor TF, de la Fuente JR, Saunders J, et al. AUDIT: the Alcohol Use Disorders Identification Test, Guidelines for use in primary health care. Geneva: World Health Organization, 1992.</p> <p>Sayer GP, Britt H, Horn F, et al. Measures of health and health care delivery in general practice in Australia, AIHW catalogue number GEP-3. Canberra: The Australian Institute of Health and Welfare, 2000</p> <p>Bush K, Kivlahan DR, et al (1998). The AUDIT alcohol consumption questions (AUDIT-C): An effective brief screening test for problem drinking. <i>Ambulatory Care Quality Improvement Project (ACQUIP)</i>. <i>Arch Intern Med</i>. 158:1789-95.</p>
Self-harm	Baseline questionnaire	<p>Question related to self harm: "In the past 12 months have you ever deliberately hurt yourself or done anything that you knew might have harmed you or even killed you?"</p> <p>No Yes</p>	Patton GC, Hemphill SA, Beyers JM, et al. Pubertal stage and deliberate self-harm in adolescents. <i>J Am Acad Child Adolesc Psychiatry</i> 2007;46:508-14.
Risk perception	Baseline questionnaire	<p>Summary score derived from 10 item scale measures on 4 point Likert scale (Always safe, mostly safe, sometimes safe, rarely safe) grouped into population tertiles (low, medium and high) for analysis</p> <p>10 items:</p> <ul style="list-style-type: none"> • Driving with 2 or more passengers • Driving between midnight and 6 AM • Driving at 110 km/h in a 100-km/h zone • Driving at 70 km/h in a 60-km/h zone • Driving while talking on a mobile phone • Driving a poorly maintained car • Driving with a blood alcohol level just over the legal limit 	<p>Begg DJ, Brookland R, Hope J, Langley J, Broughton J. New Zealand drivers study: developing a methodology for conducting a follow-up study of newly licensed drivers. <i>J Safety Res</i>. 2003;34:329–336.</p> <p>Donovan J, Jessor R. Young Adult Driving Questionnaire. Boulder: Colorado Institute of Behavioral Science; 1992</p>

Variable	Source	Category / unit in the analysis	Reference
		<ul style="list-style-type: none"> • Driving while using SMS on a mobile phone • Driving after smoking marijuana • Going through a red light 	
Risk taking	Baseline questionnaire	<p>Summary score derived from 14 item scale measures on 5 point Likert scale (Never, hardly ever, sometimes, often and very often) grouped into population tertiles (low, medium and high) for analysis</p> <p>10 items:</p> <ul style="list-style-type: none"> • Drive fast just for the thrill of it • Take some risks when driving • Drive 70km/h in a 60km/h zone • Do burnouts, donuts, or skids • Speed up if someone is trying to pass you • Follow very close behind slower drivers • Make rude gestures at other drivers • Honk your horn or flash your lights • Race or drag race • Drive while talking on a mobile phone • Drive while listening to loud music • Drive with 2 or more passengers • Drive while using SMS on a mobile phone • Drive without wearing a seatbelt 	Begg D, Brookland R, Hope J, Langley J, Broughton J. New Zealand drivers study: developing a methodology for conducting a follow-up study of newly licensed drivers. <i>Journal of safety research</i> 2003; 34(3): 329-36.
Sensation seeking	Baseline questionnaire	<p>Summary score derived from 20 item scale measures (Yes/No) grouped into population tertiles (low, medium and high) for analysis.</p> <ul style="list-style-type: none"> • I tend to begin a new job without much advance • planning on how I will do it • I usually think about what I am going to do before I do it • I often do things on impulse • I very seldom spend much time on the details of planning ahead • I like to have new and exciting experiences and sensations even if they are a little frightening • Before I begin a complicated job, I make careful plans • I would like to take off on a trip with no pre-planned or definite routes or timetables • I enjoy getting into new situations where you can't predict how things will turn out • I like doing things just for the thrill of it • I tend to change interests frequently • I sometimes like to do things that are a little frightening • I'll try anything once • I would like the kind of life where one is on the move and travelling a lot, with lots of change and excitement 	<p>Impulsive Sensation Seeking Scale of the Zuckerman–Kuhlman Personality Questionnaire</p> <p>Zuckerman M, Kuhlman DM, Joireman J, et al. A comparison of the three structural models for personality: the big three, the big five, and the alternative five. <i>J Pers Soc Psychol</i> 1993;65:757–68.</p>

Variable	Source	Category / unit in the analysis	Reference
		<ul style="list-style-type: none"> • I sometimes do 'crazy' things just for fun • I like to explore a strange city or section of town by myself, even if it means getting lost • I prefer friends who are excitingly unpredictable • I often get so carried away by new and exciting things that I never think of possible complications • I am an impulsive person • I like 'wild' uninhibited parties 	
Driving exposure	Baseline questionnaire	During an average week, about how long (to the nearest hour) do you spend driving a car?	Stevenson MR, Palamara P. Behavioural factors as predictors of motor vehicle crashes: differentials between young urban and rural drivers, Aust N Z J Public Health 2001;25:245–9. Begg D, Brookland R, Hope J, et al. New Zealand drivers study: developing a methodology for conducting a follow-up study of newly licensed drivers. J Safety Res 2003;34:329–36.

Table supplement 2: Variables included in the different models to explore the relationship between driving offences (any offence, reckless driving, speeding, low speeding and others) during 2003/04-2006 and crash (any crash, crash resulting in hospital admission or death and single vehicle crash) during 2007-2016.

Model	Variables included
M1*	age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence and average driving per week
M2*	age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence average driving per week, cannabis smoking, alcohol consumption, drug use and self-harm
M3*	age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence, average driving per week, risk perception score, risky driving score and sensation seeking score.
M4*	age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence, average driving per week, self-rated driving ability, number of attempts on driver test, crash before start of follow up not related to driving offence, lessons with professional driving instructor and time on learner licence.
M5*	age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence, average driving per week, cannabis smoking, alcohol consumption, drug use and self-harm, risk perception score, risky driving score, sensation seeking score, self-rated driving ability, number of attempts on driver test, crash before start of follow up not related to driving offence, lessons with professional driving instructor and time on learner licence

*adjusted for all other driving offences (calculated as number of any offence minus offence under investigation)

^ Variables were entered into the model in the format shown in Table 1

Table supplement 3: Cohort characteristics by number of driving reckless driving related offences.*

		None	One	
		Number (%)	Number (%)	Total
Sex	Female	11005 (55.9)	344 (31.6)	11349 (54.6)
	Male	8689 (44.1)	743 (68.4)	9432 (45.4)
Age (years)	17	9480 (48.1)	638 (58.7)	10118 (48.7)
	18-19	7374 (37.4)	354 (32.6)	7728 (37.2)
	20-25	2840 (14.4)	95 (8.7)	2935 (14.1)
Country of birth	Australia / NZ	16879 (87.3)	982 (91.3)	17861 (87.5)
	Other	2456 (12.7)	94 (8.7)	2550 (12.5)
Area level SES	Least	4915 (25.0)	216 (19.9)	5131 (24.7)
	Second quartile	4896 (24.9)	237 (21.8)	5133 (24.7)
	Third quartile	5118 (26.0)	329 (30.3)	5447 (26.2)
	Most	4765 (24.2)	305 (28.1)	5070 (24.4)
Remoteness	Metro	14674 (74.5)	778 (71.6)	15452 (74.4)
	Inner regional	4136 (21.0)	252 (23.2)	4388 (21.1)
	Outer regional /	884 (4.5)	57 (5.2)	941 (4.5)
Attempts driver test	1	12800 (65.2)	672 (61.9)	13472 (65.0)
	2	4689 (23.9)	267 (24.6)	4956 (23.9)
	3 or more	2139 (10.9)	146 (13.5)	2285 (11.0)
Time on I-Licence	< 1 year	7436 (37.9)	490 (45.2)	7926 (38.3)
	1-1.5 years	7004 (35.7)	400 (36.9)	7404 (35.8)
	> 1.5 years	5176 (26.4)	194 (17.9)	5370 (25.9)
Crash before study	No	19168 (97.3)	999 (91.9)	20167 (97.0)
	Yes	526 (2.7)	88 (8.1)	614 (3.0)
Self-rated driving ability compared to other drivers	Much better	3467 (18.2)	261 (25.3)	3728 (18.6)
	Better	8333 (43.8)	425 (41.2)	8758 (43.6)
	Same	6910 (36.3)	332 (32.2)	7242 (36.1)
	Worse or much	328 (1.7)	14 (1.4)	342 (1.7)
Marijuana smoking in last 12 months	Never	16456 (86.5)	807 (78.1)	17263 (86.1)
	Once a month or	1945 (10.2)	146 (14.1)	2091 (10.4)
	2-4 times a	359 (1.9)	41 (4.0)	400 (2.0)
	2-3 or 4plus per	258 (1.4)	39 (3.8)	297 (1.5)
Use of other drugs in last 12 months	Never	17716 (93.3)	933 (90.8)	18649 (93.2)
	Once a month or	967 (5.1)	64 (6.2)	1031 (5.2)
	2-4 times a	212 (1.1)	24 (2.3)	236 (1.2)
	2-3 or 4plus per	89 (0.5)	6 (0.6)	95 (0.5)
Alcohol audit summary score	No	16620 (87.2)	818 (78.9)	17438 (86.8)
	Yes	2437 (12.8)	219 (21.1)	2656 (13.2)
Self-harm	No	17096 (92.4)	873 (87.4)	17969 (92.1)
	Yes	1414 (7.6)	126 (12.6)	1540 (7.9)
Risk Taking	Low	6645 (35.5)	205 (20.3)	6850 (34.7)
	Medium	6161 (32.9)	290 (28.8)	6451 (32.7)
	High	5938 (31.7)	513 (50.9)	6451 (32.7)
Risk perception	Low	5964 (32.0)	245 (24.4)	6209 (31.6)
	Medium	5876 (31.5)	271 (27.0)	6147 (31.3)
	High	6800 (36.5)	487 (48.6)	7287 (37.1)
Sensation score	Low	6059 (32.5)	198 (19.8)	6257 (31.9)
	Medium	6076 (32.6)	310 (30.9)	6386 (32.5)
	High	6501 (34.9)	494 (49.3)	6995 (35.6)
Average weekly driving (hours)	Mean (SD)	8.5 (13.0)	12.5 (25.6)	8.7 (13.9)
Lessons with professional driving instructor (hours)	0	3406 (17.3)	248 (22.8)	3654 (17.6)
	1-4	5584 (28.4)	325 (29.9)	5909 (28.4)
	5-8	4061 (20.6)	230 (21.2)	4291 (20.6)
	9+	6643 (33.7)	284 (26.1)	6927 (33.3)

* Offences from joining DRIVE study in 2003/04 till end of 2006.

Table supplement 4: Cohort characteristics by number of low speeding related offences.*

		None Number (%)	One Number (%)	Total
Sex	Female	10170 (55.4)	1179 (48.4)	11349 (54.6)
	Male	8176 (44.6)	1256 (51.6)	9432 (45.4)
Age (years)	17	8840 (48.2)	1278 (52.5)	10118 (48.7)
	18-19	6852 (37.3)	876 (36.0)	7728 (37.2)
	20-25	2654 (14.5)	281 (11.5)	2935 (14.1)
Country of birth	Australia / NZ	15687 (87.1)	2174 (90.4)	17861 (87.5)
	Other	2319 (12.9)	231 (9.6)	2550 (12.5)
Area level SES	Least	4621 (25.2)	510 (20.9)	5131 (24.7)
	Second quartile	4517 (24.6)	616 (25.3)	5133 (24.7)
	Third quartile	4772 (26.0)	675 (27.7)	5447 (26.2)
	Most	4436 (24.2)	634 (26.0)	5070 (24.4)
Remoteness	Metro	13681 (74.6)	1771 (72.7)	15452 (74.4)
	Inner regional	3835 (20.9)	553 (22.7)	4388 (21.1)
	Outer regional /	830 (4.5)	111 (4.6)	941 (4.5)
Attempts driver test	1	11913 (65.2)	1559 (64.2)	13472 (65.0)
	2	4377 (23.9)	579 (23.8)	4956 (23.9)
	3 or more	1993 (10.9)	292 (12.0)	2285 (11.0)
Time on I-Licence	< 1 year	6899 (37.8)	1027 (42.3)	7926 (38.3)
	1-1.5 years	6536 (35.8)	868 (35.8)	7404 (35.8)
	> 1.5 years	4838 (26.5)	532 (21.9)	5370 (25.9)
Crash before study	No	17932 (97.7)	2235 (91.8)	20167 (97.0)
	Yes	414 (2.3)	200 (8.2)	614 (3.0)
Self-rated driving ability compared to other drivers	Much better	3258 (18.4)	470 (20.1)	3728 (18.6)
	Better	7720 (43.5)	1038 (44.5)	8758 (43.6)
	Same	6448 (36.4)	794 (34.0)	7242 (36.1)
	Worse or much	309 (1.7)	33 (1.4)	342 (1.7)
Marijuana smoking in last 12 months	Never	15383 (86.8)	1880 (80.6)	17263 (86.1)
	Once a month or	1781 (10.1)	310 (13.3)	2091 (10.4)
	2-4 times a	326 (1.8)	74 (3.2)	400 (2.0)
	2-3 or 4plus per	229 (1.3)	68 (2.9)	297 (1.5)
Use of other drugs in last 12 months	Never	16539 (93.5)	2110 (90.5)	18649 (93.2)
	Once a month or	876 (5.0)	155 (6.6)	1031 (5.2)
	2-4 times a	188 (1.1)	48 (2.1)	236 (1.2)
	2-3 or 4plus per	77 (0.4)	18 (0.8)	95 (0.5)
Alcohol audit summary score	No	15529 (87.4)	1909 (81.8)	17438 (86.8)
	Yes	2230 (12.6)	426 (18.2)	2656 (13.2)
Self-harm	No	15928 (92.3)	2041 (90.5)	17969 (92.1)
	Yes	1326 (7.7)	214 (9.5)	1540 (7.9)
Risk Taking	Low	6331 (36.2)	519 (22.7)	6850 (34.7)
	Medium	5718 (32.7)	733 (32.1)	6451 (32.7)
	High	5417 (31.0)	1034 (45.2)	6451 (32.7)
Risk perception	Low	5595 (32.2)	614 (27.0)	6209 (31.6)
	Medium	5470 (31.5)	677 (29.8)	6147 (31.3)
	High	6305 (36.3)	982 (43.2)	7287 (37.1)
Sensation score	Low	5726 (33.0)	531 (23.4)	6257 (31.9)
	Medium	5672 (32.7)	714 (31.4)	6386 (32.5)
	High	5969 (34.4)	1026 (45.2)	6995 (35.6)
Average weekly driving (hours)	Mean (SD)	8.5 (14.1)	10.7 (12.9)	8.7 (13.9)
Lessons with professional driving instructor (hours)	0	3184 (17.4)	470 (19.3)	3654 (17.6)
	1-4	5172 (28.2)	737 (30.3)	5909 (28.4)
	5-8	3778 (20.6)	513 (21.1)	4291 (20.6)
	9+	6212 (33.9)	715 (29.4)	6927 (33.3)

* Offences from joining DRIVE study in 2003/04 till end of 2006.

Table supplement 5: Cohort characteristics by number of speeding related offences.*

		None	One	Two	Total
		Number (%)	Number (%)	Number (%)	
Sex	Female	9201 (58.7)	1703 (44.7)	445 (34.5)	11,349
	Male	6483 (41.3)	2103 (55.3)	846 (65.5)	9,432
Age (years)	17	7351 (46.9)	2064 (54.2)	703 (54.5)	10,118
	18-19	5905 (37.6)	1357 (35.7)	466 (36.1)	7,728
	20-25	2428 (15.5)	385 (10.1)	122 (9.5)	2,935
Country of birth	Australia / NZ	13347 (86.8)	3366 (89.6)	1148 (90.3)	17,861
	Other	2037 (13.2)	390 (10.4)	123 (9.7)	2,550
Area level SES	Least disadvantaged	4072 (26.0)	814 (21.4)	245 (19.0)	5,131
	Second quartile	3855 (24.6)	942 (24.8)	336 (26.0)	5,133
	Third quartile	4017 (25.6)	1049 (27.6)	381 (29.5)	5,447
	Most disadvantaged	3740 (23.8)	1001 (26.3)	329 (25.5)	5,070
Remoteness	Metro	11711 (74.7)	2782 (73.1)	959 (74.3)	15,452
	Inner regional	3263 (20.8)	844 (22.2)	281 (21.8)	4,388
	Outer regional / remote	710 (4.5)	180 (4.7)	51 (4.0)	941
Attempts driver test	1	10214 (65.4)	2473 (65.1)	785 (60.9)	13,472
	2	3714 (23.8)	907 (23.9)	335 (26.0)	4,956
	3 or more	1701 (10.9)	416 (11.0)	168 (13.0)	2,285
Time on I-Licence	< 1 year	5682 (36.4)	1666 (43.9)	578 (44.9)	7,926
	1-1.5 years	5586 (35.8)	1353 (35.7)	465 (36.2)	7,404
	> 1.5 years	4352 (27.9)	775 (20.4)	243 (18.9)	5,370
Crash before study	No	15464 (98.6)	3527 (92.7)	1176 (91.1)	20,167
	Yes	220 (1.4)	279 (7.3)	115 (8.9)	614
Self-rated driving ability compared to other drivers	Much better	2634 (17.3)	797 (21.8)	297 (24.0)	3,728
	Better	6614 (43.6)	1600 (43.8)	544 (44.0)	8,758
	Same	5657 (37.3)	1212 (33.2)	373 (30.2)	7,242
	worse or much worse	278 (1.8)	42 (1.2)	22 (1.8)	342
Marijuana smoking in last 12 months	Never	13310 (87.7)	3023 (82.9)	930 (75.5)	17,263
	Once a month or less	1434 (9.5)	455 (12.5)	202 (16.4)	2,091
	2-4 times a month	250 (1.6)	99 (2.7)	51 (4.1)	400
	2-3 or 4plus per week	178 (1.2)	70 (1.9)	49 (4.0)	297
Use of other drugs in last 12 months	Never	14231 (94.0)	3331 (91.6)	1087 (88.5)	18,649
	Once a month or less	706 (4.7)	232 (6.4)	93 (7.6)	1,031
	2-4 times a month	148 (1.0)	54 (1.5)	34 (2.8)	236
	2-3 or 4plus per week	61 (0.4)	20 (0.5)	14 (1.1)	95
Alcohol audit summary score	No	13456 (88.5)	3014 (82.5)	968 (78.3)	17,438
	Yes	1749 (11.5)	638 (17.5)	269 (21.7)	2,656
Self-harm	No	13718 (92.8)	3205 (90.3)	1046 (88.4)	17,969
	Yes	1060 (7.2)	343 (9.7)	137 (11.6)	1,540
Risk Taking	Low	5840 (39.0)	809 (22.6)	201 (16.6)	6,850
	Medium	4971 (33.2)	1154 (32.2)	326 (26.9)	6,451
	High	4146 (27.7)	1618 (45.2)	687 (56.6)	6,451
Risk perception	Low	5015 (33.7)	927 (26.0)	267 (22.2)	6,209
	Medium	4753 (32.0)	1085 (30.4)	309 (25.7)	6,147
	High	5105 (34.3)	1554 (43.6)	628 (52.2)	7,287
Sensation score	Low	5170 (34.7)	842 (23.7)	245 (20.4)	6,257
	Medium	4902 (32.9)	1142 (32.1)	342 (28.5)	6,386
	High	4810 (32.3)	1571 (44.2)	614 (51.1)	6,995
Average weekly	Mean (SD)	8.0 (13.0)	10.4 (16.8)	12.7 (14.3)	8.7 (13.9)
Lessons with professional driving instructor (hours)	0	2643 (16.9)	729 (19.2)	282 (21.8)	3,654
	1-4	4317 (27.5)	1191 (31.3)	401 (31.1)	5,909
	5-8	3224 (20.6)	833 (21.9)	234 (18.1)	4,291
	9+	5500 (35.1)	1053 (27.7)	374 (29.0)	6,927

* Offences from joining DRIVE study in 2003/04 till end of 2006.

Table supplement 6: Cohort characteristics by number of other driving offences.*

		None Number (%)	One Number (%)	Total
Sex	Female	9812 (58.3)	1537 (38.8)	11349 (54.6)
	Male	7010 (41.7)	2422 (61.2)	9432 (45.4)
Age (years)	17	8137 (48.4)	1981 (50.0)	10118 (48.7)
	18-19	6265 (37.2)	1463 (37.0)	7728 (37.2)
	20-25	2420 (14.4)	515 (13.0)	2935 (14.1)
Country of birth	Australia / NZ	14428 (87.4)	3433 (88.2)	17861 (87.5)
	Other	2089 (12.6)	461 (11.8)	2550 (12.5)
Area level SES	Least	4294 (25.5)	837 (21.1)	5131 (24.7)
	Second quartile	4178 (24.8)	955 (24.1)	5133 (24.7)
	Third quartile	4310 (25.6)	1137 (28.7)	5447 (26.2)
	Most	4040 (24.0)	1030 (26.0)	5070 (24.4)
Remoteness	Metro	12513 (74.4)	2939 (74.2)	15452 (74.4)
	Inner regional	3542 (21.1)	846 (21.4)	4388 (21.1)
	Outer regional /	767 (4.6)	174 (4.4)	941 (4.5)
Attempts driver test	1	11023 (65.7)	2449 (62.0)	13472 (65.0)
	2	3967 (23.7)	989 (25.1)	4956 (23.9)
	3 or more	1776 (10.6)	509 (12.9)	2285 (11.0)
Time on I-Licence	< 1 year	6259 (37.4)	1667 (42.3)	7926 (38.3)
	1-1.5 years	6056 (36.1)	1348 (34.2)	7404 (35.8)
	> 1.5 years	4441 (26.5)	929 (23.6)	5370 (25.9)
Crash before study	No	16501 (98.1)	3666 (92.6)	20167 (97.0)
	Yes	321 (1.9)	293 (7.4)	614 (3.0)
Self-rated driving ability compared to other drivers	Much better	2805 (17.2)	923 (24.3)	3728 (18.6)
	Better	7099 (43.6)	1659 (43.8)	8758 (43.6)
	Same	6085 (37.4)	1157 (30.5)	7242 (36.1)
	Worse or much	289 (1.8)	53 (1.4)	342 (1.7)
Marijuana smoking in last 12 months	Never	14237 (87.5)	3026 (80.0)	17263 (86.1)
	Once a month or	1573 (9.7)	518 (13.7)	2091 (10.4)
	2-4 times a	274 (1.7)	126 (3.3)	400 (2.0)
	2-3 or 4plus per	185 (1.1)	112 (3.0)	297 (1.5)
Use of other drugs in last 12 months	Never	15277 (94.1)	3372 (89.4)	18649 (93.2)
	Once a month or	747 (4.6)	284 (7.5)	1031 (5.2)
	2-4 times a	152 (0.9)	84 (2.2)	236 (1.2)
	2-3 or 4plus per	63 (0.4)	32 (0.8)	95 (0.5)
Alcohol audit summary score	No	14341 (88.0)	3097 (81.6)	17438 (86.8)
	Yes	1956 (12.0)	700 (18.4)	2656 (13.2)
Self-harm	No	14663 (92.6)	3306 (89.9)	17969 (92.1)
	Yes	1168 (7.4)	372 (10.1)	1540 (7.9)
Risk Taking	Low	5997 (37.4)	853 (22.9)	6850 (34.7)
	Medium	5290 (33.0)	1161 (31.1)	6451 (32.7)
	High	4733 (29.5)	1718 (46.0)	6451 (32.7)
Risk perception	Low	5260 (33.0)	949 (25.7)	6209 (31.6)
	Medium	5071 (31.8)	1076 (29.1)	6147 (31.3)
	High	5617 (35.2)	1670 (45.2)	7287 (37.1)
Sensation score	Low	5425 (34.0)	832 (22.5)	6257 (31.9)
	Medium	5234 (32.8)	1152 (31.2)	6386 (32.5)
	High	5285 (33.1)	1710 (46.3)	6995 (35.6)
Average weekly	Mean (SD)	8.0 (12.5)	11.7 (18.6)	8.7 (13.9)
Lessons with professional driving instructor (hours)	0	2805 (16.7)	849 (21.4)	3654 (17.6)
	1-4	4719 (28.1)	1190 (30.1)	5909 (28.4)
	5-8	3539 (21.0)	752 (19.0)	4291 (20.6)
	9+	5759 (34.2)	1168 (29.5)	6927 (33.3)

* Offences from joining DRIVE study in 2003/04 till end of 2006.

Table supplement 7: Rate ratios[#] of any crash, hospitalised crash or death and single vehicle crash during 2007-2016 by type of driving offence 2003-2006.

			M1 demographics and driving exposure RR (95% CI)	M2 M1 +drugs & self-harm RR (95% CI)	M3 M1+risk- taking RR (95% CI)	M4 M1+ Training / experience / previous crash RR (95% CI)	M5 Fully adjusted RR (95% CI)	
Any crash	Any offence	One	1.34 (1.22-1.48)	1.35 (1.23-1.49)	1.34 (1.22-1.48)	1.34 (1.22-1.48)	1.35 (1.22-1.49)	
		Two	1.48 (1.30-1.69)	1.50 (1.32-1.71)	1.49 (1.31-1.70)	1.48 (1.30-1.69)	1.50 (1.31-1.71)	
		Three or more	2.22 (1.96-2.52)	2.26 (1.99-2.57)	2.25 (1.98-2.56)	2.22 (1.95-2.52)	2.25 (1.98-2.57)	
	Reckless driving*	One or more	1.35 (1.18-1.56)	1.36 (1.18-1.56)	1.36 (1.18-1.57)	1.35 (1.18-1.56)	1.35 (1.17-1.56)	
	Speeding*	One	1.24 (1.12-1.36)	1.24 (1.13-1.37)	1.24 (1.12-1.37)	1.24 (1.12-1.36)	1.24 (1.13-1.37)	
		Two or more	1.57 (1.37-1.81)	1.59 (1.38-1.83)	1.59 (1.38-1.83)	1.57 (1.36-1.81)	1.59 (1.38-1.83)	
	Low speeding offence*	One or more	1.06 (0.95-1.19)	1.07 (0.95-1.20)	1.07 (0.95-1.20)	1.06 (0.95-1.19)	1.07 (0.95-1.20)	
	Other offences*	One or more	1.42 (1.27-1.60)	1.43 (1.27-1.60)	1.43 (1.27-1.60)	1.42 (1.27-1.59)	1.43 (1.28-1.61)	
	Hospitalised crash or death	Any offence	One	1.52 (0.99-2.34)	1.52 (0.99-2.35)	1.52 (0.98-2.36)	1.51 (0.98-2.34)	1.52 (0.97-2.36)
			Two	1.75 (0.98-3.11)	1.76 (0.98-3.14)	1.75 (0.98-3.14)	1.76 (0.98-3.16)	1.76 (0.98-3.18)
Three or more			2.83 (1.58-5.05)	2.88 (1.59-5.22)	2.85 (1.59-5.12)	2.81 (1.58-4.98)	2.87 (1.60-5.17)	
Reckless driving*		One or more	3.00 (1.81-4.95)	2.98 (1.80-4.93)	3.05 (1.85-5.03)	2.99 (1.82-4.92)	3.00 (1.83-4.92)	
Speeding*		One	1.07 (0.67-1.72)	1.08 (0.67-1.73)	1.08 (0.67-1.73)	1.08 (0.67-1.73)	1.09 (0.68-1.74)	
		Two or more	1.43 (0.75-2.71)	1.44 (0.75-2.76)	1.47 (0.77-2.78)	1.43 (0.76-2.72)	1.47 (0.77-2.79)	
Low speeding offence*		One or more	1.34 (0.82-2.18)	1.35 (0.83-2.20)	1.34 (0.83-2.17)	1.33 (0.82-2.15)	1.33 (0.82-2.16)	
Other offences*		One or more	1.71 (1.01-2.89)	1.72 (1.02-2.92)	1.71 (1.01-2.90)	1.70 (1.01-2.88)	1.77 (1.06-2.96)	
Single vehicle crash		Any offence	One	1.59 (1.17-2.17)	1.61 (1.18-2.19)	1.61 (1.18-2.20)	1.60 (1.17-2.19)	1.62 (1.18-2.23)
			Two	1.94 (1.32-2.86)	1.98 (1.34-2.92)	2.01 (1.36-2.97)	1.95 (1.32-2.88)	2.03 (1.36-3.01)
	Three or more		3.16 (2.22-4.52)	3.19 (2.21-4.59)	3.31 (2.31-4.76)	3.19 (2.24-4.53)	3.28 (2.28-4.72)	
	Reckless driving*	One or more	1.32 (0.88-1.99)	1.31 (0.87-1.97)	1.35 (0.90-2.03)	1.32 (0.88-1.99)	1.32 (0.88-1.99)	
	Speeding*	One	1.39 (1.03-1.86)	1.40 (1.04-1.88)	1.41 (1.04-1.90)	1.39 (1.03-1.88)	1.42 (1.05-1.92)	
		Two or more	1.86 (1.26-2.74)	1.87 (1.26-2.77)	1.91 (1.29-2.84)	1.87 (1.27-2.75)	1.92 (1.29-2.85)	
	Low speeding offence*	One or more	1.04 (0.74-1.46)	1.04 (0.74-1.46)	1.06 (0.75-1.48)	1.05 (0.75-1.47)	1.05 (0.75-1.48)	
	Other offences*	One or more	1.90 (1.37-2.64)	1.89 (1.35-2.63)	1.93 (1.38-2.69)	1.90 (1.36-2.64)	1.90 (1.36-2.66)	

[#]Model adjusted for^a

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

M2: age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence average driving per week, cannabis smoking, alcohol consumption, drug use and self-harm

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

M4: age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence, average driving per week, self-rated driving ability, number of attempts on driver test, crash before start of follow up not related to driving offence, lessons with professional driving instructor and time on learner licence.

M5: age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence, average driving per week, cannabis smoking, alcohol consumption, drug use and self-harm, risk perception score, risky driving score, sensation seeking score, self-rated driving ability, number of attempts on driver test, crash before start of follow up not related to driving offence, lessons with professional driving instructor and time on learner licence

^aadjusted for all other driving offences (calculated as number of any offence minus offence under investigation)

