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Risky youth to risky adults: Sustained increased risk of crash in the DRIVE study 13 years on

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ABSTRACT

The objective of this study was to investigate if drivers who exhibit risky driving behaviours during youth (aged 17–24 years) have an increased risk of car crash up to 13 years later.

We used data from the DRIVE study, a 2003/04 survey of 20,806 young novice drivers in New South Wales, Australia. The data were linked with police crash, hospital and deaths data up to 2016. We analysed differences in crash associated with 13 items of risky driving behaviours using negative binominal regression models adjusted for driver demographics, driving exposure and known crash risk factors. The items were summarised in one index and grouped into quintiles for the analysis.

After adjusting for confounding, drivers of the third (RR 1.16, 95% CI 1.05–1.30), fourth (RR1.22, 95% CI1.09–1.36) and fifth quintile (RR 1.36, 95% CI 1.21–1.53) had higher crash rates compared to the lowest risk-takers. Drivers with the highest scores on the risky driving measure had higher rates of crash related hospital admission or death (RR 1.92, 95% CI 1.13–3.27), crashes in wet conditions (RR 1.35,95% CI 1.05–1.73), crashes in darkness (RR 1.55, 95% CI 1.25–1.93) and head-on crashes (RR 2.14, 95% CI 1.07–4.28), compared with drivers with the lowest scores.

Novice adolescent drivers who reported high levels of risky driving when they first obtained a driver licence remained at increased risk of crash well into adulthood. Measures that successfully reduce early risky driving, have the potential to substantially reduce road crashes and transport related injuries and deaths over the lifespan.

1. Introduction

Deaths and injury from road transport crashes remain a major challenge to public health in Australia and worldwide (World Health Organisation, 2018). Although road safety has long been a policy priority, success in reducing death and injury from road crashes has stalled in recent years. (Transport and infrastructure council, 2018; World Health Organisation, 2017; United Nations General Assembly, 2018; United Nations. Road Safety-Considerations in Support of the, 2030)

Novice drivers and especially young novice drivers are at particular risk of car crash, experiencing death and injury at around double the rate of the rest of the population (Curry et al., 2015; Australian Institute of Health and Welfare, 2018). Graduated driver licensing schemes have been designed and implemented to decrease risk of crash in novice drivers (Senserrick and Williamson, 2015), and while these have had some success, there is more work to do to address the disproportionate crash and injury burden in young drivers. Knowledge of crash risk factors and their magnitude as well as the within-population groups at high risk of crash is essential for the design of targeted injury prevention measures. This information can be used to estimate the impact of injury prevention measures, using for example the Global Burden of Disease study framework for comparative risk assessment (Stanaway et al., 2018).

Crash risk factors are multifactorial and are commonly grouped into

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human, infrastructure and vehicle factors (Ivers et al., 2009; Dingus et al., 2016; Talbot et al., 2016). Risky driving behaviours, such as racing and rule violations and distraction through for example mobile phone use, are leading modifiable crash risk factors at the driver level (Ivers et al., 2009; Talbot et al., 2016). Young drivers are more likely to engage in such risky driving behaviours than older drivers and this has in turn been linked to an increased risk of crash (Ivers et al., 2009; Turner and McClure, 2003; Fergusson et al., 2003).

High-risk behaviour in young drivers has been explained by lack of driving experience and by imbalance in the development of the brain, with heightened reward sensitivity and immature impulse control (Lambert et al., 2014; Casey et al., 2011; Lazuras et al., 2019; Bingham et al., 2008). Risk taking peaks with the social and emotional reactions of adolescents (Patton et al., 2016) and as young drivers mature into adulthood most become more safety conscious, but some drivers continue to engage in risk-taking behaviours past the early years (Bingham et al., 2008; Vassallo et al., 2013; Begg and Langley, 2004). Evidence from longitudinal studies shows that men are more likely to engage in risky driving than women (Ivers et al., 2009) and men are also more likely to continue to engage in risky driving past the early years than women (Vassallo et al., 2013; Begg and Langley, 2004; McDonald et al., 2014). Moreover, risk-taking drivers are more likely to be aggressive, lower in constraint, report mental health problems and engage in antisocial behaviour and binge drinking more frequently than other drivers (Vassallo et al., 2013; Begg and Langley, 2004; Gulliver and Begg, 2007). As such it has been suggested that driver risk-taking may form part of a broader underlying tendency to engage in problem behaviour (Jessor, 2018).

Despite the growing evidence from these studies that some drivers keep engaging in risky driving past adolescence (Vassallo et al., 2013; Begg and Langley, 2004; Gulliver and Begg, 2007), it is not known if this also translates into a higher risk of crash and if the risk of crash is greater for drivers who also engage in other risk taking behaviours or have mental health problems. Previous analysis of the DRIVE Study, a NSW cohort study of young novice drivers, showed that drivers reporting high levels of risk-taking behaviours had a 50% increased crash rates compared with lower risk-taking drivers during the first two years after obtaining their driver licence (Ivers et al., 2009). Recent relinkage of the of the DRIVE cohort survey data with crash, hospital and death data allowed investigation if the observed higher crash rate among high risk takers persists past the initial two years of driving.

In this study we aimed to investigate if drivers who exhibit high risk-taking behaviour during youth (aged 17–24) have increased rates of crash up to 13 years later and if this varies by type and severity of crash. Moreover, we aimed to investigate how many crashes could be avoided if measures were implemented that successfully reduce risky driving behaviours when first identified during the early years of driving.

2. Methods

2.1. Study design and setting

The DRIVE Study is a prospective cohort study and was conducted in New South Wales (NSW), Australia. NSW is the most populous state with 7.5million residents (Australian Bureau of Statistics, 2016), and with 4.28 million, has the largest number of registered passenger vehicles of any state in Australia (Australian Bureau of Statistics, 2018).

2.2. Data sources

The DRIVE study baseline data was collected via a 2003/04 survey of 20,822 young drivers aged 17–24 years holding their first-stage provisional motor vehicle driver's licence from NSW, Australia (Ivers et al., 2006). The DRIVE study collected information on driver demographics, driving exposure, driving experience and training, and known and hypothesised crash risk factors such as risk perception, risky driving behaviour (Ivers et al., 2009), mental health status and drug and alcohol use (Table 1) (Ivers et al., 2006). The study cohort comprised of 20,806 participants after excluding 16 duplicate records. Data collection and the study cohort have been described in detail elsewhere (Ivers et al., 2006).

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

The NSW Centre for Road Safety CrashLink system provides information on all persons injured or killed due to road crashes that occur on NSW classified and local roads.

The Admitted Patient Data Collection (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 (ICD-10-AM) (National Centre for Classification in Health., 2008).

The NSW Registry of Births, Deaths and Marriages (RBDM) contains information on all deaths in NSW. The ABS cause of death data includes information derived from the deaths certificate or coronial report on the cause of deaths.

2.3. Variables in the analysis

The study outcome measures were total number of crashes (police recorded crash, crash resulting in hospitalisation or death), crash related hospitalisations or deaths, single vehicle crashes, crashes in wet or dark conditions and head-on crashes during the follow-up time from 2003 to 2016. These outcomes were chosen to capture all crash events, the most severe crashes, crashes where the driver is most likely at fault and those that might be related to risky driving in adverse conditions.

The data 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 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 risky driving behaviour. This was derived from the baseline survey which included 14 items adapted from previous research (Begg et al., 2003) (Supplement Table 1 and 2). Participants were asked, "How often do you engage in a particular behaviour?"; possible responses and corresponding scores were: very often = 4, often = 3, sometimes = 2, hardly ever = 1, and never = 0.

Principal factor analysis was used to identify groups of risky driving behaviours. Appropriateness of factor analysis was tested using the Kaiser-Meyer-Olkin test for sampling adequacy (0.89) and the Bartlett's test for sphericity ($p < 0.001$) (Supplement Table 3). Cronbach's Alpha was calculated to assess internal consistency. Explorative factor analysis identified a one factor model with 13 items to be the best fit (Supplement Table 4 and Fig. 1); this explained 88.6% of the total variance and internal consistency was high (Cronbach's alpha 0.86). Driving with no seatbelt was excluded as it had low factor loading (0.24). A weighted index derived through regression scoring was created for use in the analysis and. For the analysis risky driving was split into population quintiles. 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), self-harm, driver training and experience (supervised driving hours, months on learner licence, number of attempts on learner licence, self-rated driving ability, months

Table 1
Cohort characteristics by risky driving quintile, the DRIVE study, NSW, Australia, June 2003–December 2004*.

Variable	Category	Lowest (*n* = 3995)	Second quintile (n = 3995)	Third quintile (n = 3995)	Fourth quintile (n = 3995)	Highest (n = 3995)	Total (*N* = 20,806)
		Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)
Age group	17	1659 (42.0)	1810 (45.8)	1870 (47.3)	2042 (51.6)	2238 (56.6)	10,128 (48.7)
	18–19	1429 (36.1)	1484 (37.5)	1540 (38.9)	1489 (37.7)	1434 (36.3)	7741 (37.2)
	20–25	867 (21.9)	661 (16.7)	545 (13.8)	424 (10.7)	283 (7.2)	2937 (14.1)
Gender	Female	2601 (65.8)	2496 (63.1)	2260 (57.1)	1984 (50.2)	1420 (35.9)	11,357 (54.6)
	Male	1354 (34.2)	1459 (36.9)	1695 (42.9)	1971 (49.8)	2535 (64.1)	9449 (45.4)
Country of birth	Australia & new Zealand	3323 (84.0)	3413 (86.3)	3410 (86.2)	3424 (86.6)	3440 (87.0)	17,883 (86.0)
	Europe	39 (1.0)	37 (0.9)	45 (1.1)	42 (1.1)	50 (1.3)	220 (1.1)
	Asia	503 (12.7)	442 (11.2)	431 (10.9)	436 (11.0)	400 (10.1)	2333 (11.2)
	Missing	90 (2.3)	63 (1.6)	69 (1.7)	53 (1.3)	65 (1.6)	370 (1.8)
Remoteness	Metro	2939 (74.3)	2903 (73.4)	2888 (73.0)	2964 (74.9)	3036 (76.8)	15,463 (74.3)
	Inner regional	831 (21.0)	851 (21.5)	894 (22.6)	803 (20.3)	785 (19.9)	4399 (21.1)
	Outer regional / remote	185 (4.7)	201 (5.1)	173 (4.4)	188 (4.8)	134 (3.4)	944 (4.5)
SEIFA education	Least disadvantaged	938 (23.7)	963 (24.4)	1008 (25.5)	1003 (25.4)	1036 (26.2)	5135 (24.7)
	2nd quartile	969 (24.5)	1006 (25.4)	967 (24.5)	984 (24.9)	969 (24.5)	5136 (24.7)
	3rd quartile	1072 (27.1)	1036 (26.2)	1008 (25.5)	1029 (26.0)	1005 (25.4)	5453 (26.2)
	Most disadvantaged	976 (24.7)	950 (24.0)	972 (24.6)	939 (23.7)	945 (23.9)	5082 (24.4)
Attempts driver test	1	2510 (63.5)	2560 (64.7)	2627 (66.4)	2569 (65.0)	2557 (64.7)	13,488 (64.8)
	2	979 (24.8)	947 (23.9)	905 (22.9)	955 (24.2)	937 (23.7)	4962 (23.9)
	3 or more	449 (11.4)	436 (11.0)	413 (10.4)	425 (10.8)	444 (11.2)	2288 (11.0)
	Missing	17 (0.4)	12 (0.3)	10 (0.3)	6 (0.2)	17 (0.4)	68 (0.3)
Time on l-Licence	< 1 year	1308 (33.1)	1387 (35.1)	1456 (36.8)	1590 (40.2)	1760 (44.5)	7934 (38.1)
	1–1.5 years	1317 (33.3)	1330 (33.6)	1417 (35.8)	1486 (37.6)	1516 (38.3)	7416 (35.6)
	> 1.5 years	1311 (33.2)	1224 (31.0)	1068 (27.0)	872 (22.1)	659 (16.7)	5375 (25.8)
	Missing	19 (0.5)	14 (0.4)	14 (0.4)	7 (0.2)	20 (0.5)	81 (0.4)
Crash before study	No	3843 (97.2)	3841 (97.1)	3841 (97.1)	3824 (96.7)	3781 (95.6)	20,112 (96.7)
	Yes	112 (2.8)	114 (2.9)	114 (2.9)	131 (3.3)	174 (4.4)	694 (3.3)
Self-rated driving ability compared to other drivers same stage	Much better	693 (17.5)	624 (15.8)	623 (15.8)	698 (17.7)	1022 (25.8)	3734 (18.0)
	Better	1655 (41.9)	1756 (44.4)	1758 (44.5)	1771 (44.8)	1697 (42.9)	8768 (42.1)
	Same	1512 (38.2)	1516 (38.3)	1513 (38.3)	1429 (36.1)	1167 (29.5)	7250 (34.9)
	Worse or much worse	95 (2.4)	58 (1.5)	58 (1.5)	56 (1.4)	68 (1.7)	342 (1.6)
	Missing	0 (0.0)	1 (0.0)	3 (0.1)	1 (0.0)	1 (0.0)	712 (3.4)
Lessons with professional driving Instructor (hours)	0	657 (16.6)	639 (16.2)	719 (18.2)	708 (17.9)	803 (20.3)	3660 (17.6)
	1–4	949 (24.0)	1112 (28.1)	1161 (29.4)	1241 (31.4)	1246 (31.5)	5915 (28.4)
	5–8	733 (18.5)	839 (21.2)	839 (21.2)	859 (21.7)	895 (22.6)	4294 (20.6)
	9+	1616 (40.9)	1365 (34.5)	1236 (31.3)	1147 (29.0)	1011 (25.6)	6937 (33.3)
Cannabis smoking in last 12 months	Never	3802 (96.1)	3620 (91.5)	3419 (86.5)	3245 (82.1)	2906 (73.5)	17,281 (83.1)
	Once a month or less	122 (3.1)	254 (6.4)	415 (10.5)	546 (13.8)	729 (18.4)	2097 (10.1)
	2–4 times a month	9 (0.2)	49 (1.2)	62 (1.6)	102 (2.6)	171 (4.3)	400 (1.9)
	2–3 or 4plus per week	14 (0.4)	26 (0.7)	46 (1.2)	61 (1.5)	142 (3.6)	297 (1.4)
	Missing	8 (0.2)	6 (0.2)	13 (0.3)	1 (0.0)	7 (0.2)	731 (3.5)
Use of other drugs in last 12 months	Never	3837 (97.0)	3773 (95.4)	3713 (93.9)	3601 (91.1)	3435 (86.9)	18,669 (89.7)
	Once a month or less	78 (2.0)	142 (3.6)	189 (4.8)	275 (7.0)	340 (8.6)	1033 (5.0)
	2–4 times a month	10 (0.3)	22 (0.6)	31 (0.8)	53 (1.3)	116 (2.9)	238 (1.1)
	2–3 or 4plus per week	12 (0.3)	6 (0.2)	9 (0.2)	18 (0.5)	48 (1.2)	95 (0.5)
	Missing	18 (0.5)	12 (0.3)	13 (0.3)	8 (0.2)	16 (0.4)	771 (3.7)
Alcohol audit summary score	0–6	3828 (96.8)	3700 (93.6)	3507 (88.7)	3300 (83.4)	2813 (71.1)	17,458 (83.9)
	>6	126 (3.2)	253 (6.4)	448 (11.3)	654 (16.5)	1141 (28.9)	2660 (12.8)
	Missing	1 (0.0)	2 (0.1)	0 (0.0)	1 (0.0)	1 (0.0)	688 (3.3)
Self-harm	No	3786 (95.7)	3689 (93.3)	3625 (91.7)	3525 (89.1)	3249 (82.2)	17,990 (86.5)
	Yes	111 (2.8)	205 (5.2)	264 (6.7)	346 (8.8)	611 (15.5)	1542 (7.4)
	Missing	58 (1.5)	61 (1.5)	66 (1.7)	84 (2.1)	95 (2.4)	1274 (6.1)
Risk perception	Low	2568 (64.9)	1684 (42.6)	1057 (26.7)	632 (16.0)	237 (6.0)	6217 (29.9)
	Medium	956 (24.2)	1431 (36.2)	1603 (40.5)	1326 (33.5)	809 (20.5)	6152 (29.6)
	High	396 (10.0)	790 (20.0)	1255 (31.7)	1951 (49.3)	2862 (72.4)	7298 (35.1)
	Missing	35 (0.9)	50 (1.3)	40 (1.0)	46 (1.2)	47 (1.2)	1139 (5.5)
Average weekly driving (hours)	0–2	1259 (31.8)	934 (23.6)	744 (18.8)	571 (14.4)	415 (10.5)	4049 (19.5)
	3–5	1297 (32.8)	1342 (33.9)	1314 (33.2)	1264 (32.0)	1030 (26.0)	6464 (31.1)
	6–9	511 (12.9)	631 (16.0)	668 (16.9)	729 (18.4)	631 (16.0)	3280 (15.8)
	10+	888 (22.5)	1048 (26.5)	1229 (31.1)	1391 (35.2)	1879 (47.5)	7013 (33.7)

* Missing values for risky driving not shown.

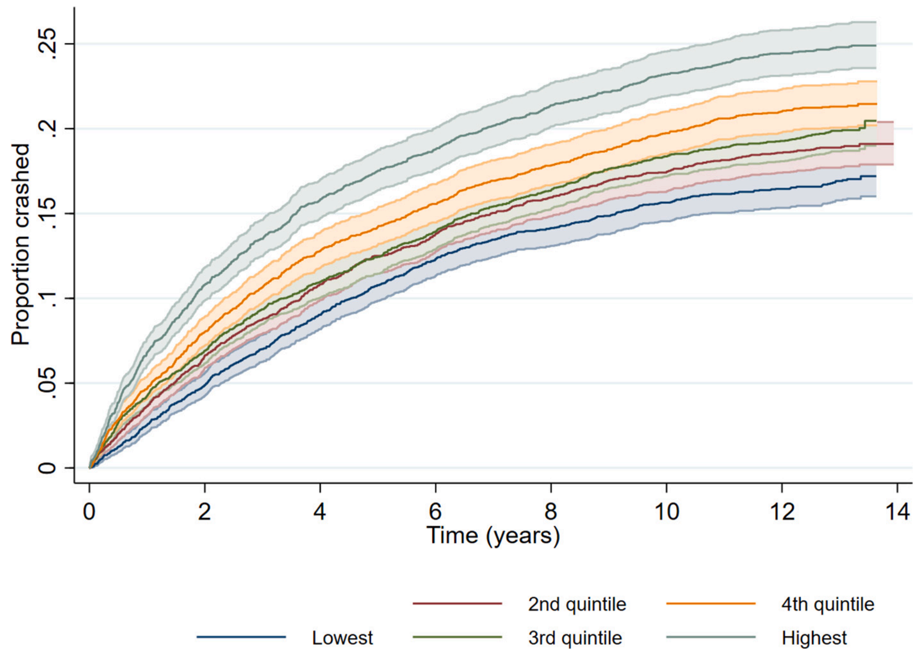

Fig. 1. Cumulative incidence curves and 95% confidence intervals* by risk-taking groups. The DRIVE study, NSW, Australia 2003–2016. *shaded areas.

between independent (provisional) driver licence and study entry, involvement in crash before study), risk perception, and driving exposure (average weekly driving) (Table 1, Supplement Table 5). Selection of co-variates for the multivariate regression model was informed by previous analyses of the DRIVE data and international studies on risk factors for crash (Ivers et al., 2009; Talbot et al., 2016; Chen et al., 2010; Boufous et al., 2010; Martiniuk et al., 2009; Hasselberg et al., 2005; Hasselberg and Laflamme, 2003).

We classified geographical remoteness of residence using the Accessibility/Remoteness index of Australia (Trewin, 2004), into three groups (metropolitan, inner regional, and outer regional and remote). We derived socioeconomic status (SES) from the Australian Bureau of Statistics 2001 area level index of education and occupation (Trewin, 2001), which was divided into NSW population quartile groups. We linked remoteness and SES information to the survey data by matching postal area.

2.4. Statistical analysis

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

We examined time to first crash for quintiles of risky driving behaviour using cumulative incidence curves. We quantified the association between risky driving and crash using negative binominal regression models.

We included time between survey (2003–2004) and end of follow-up (31.12.2016) as an offset variable in the regression models to account for different length of exposure. We censored participants who died during follow-up ($n = 72$) at the date of deaths. The influence of crash risk factors on differences in crash by risky driving group was investigated by adding measures of alcohol and drug use and self-harm (Model 2), risk perception (Model 3), driver training and experience (Model 4) and all of these measures combined (Model 5) to the model adjusted for demographic factors and driving exposure (Model 1).

The joint effect of risky driving and other risk-taking behaviours (drug, cannabis and alcohol use) as well as risk perception and self-harm, which have previously been linked with risky driving, on crash was explored by fitting the fully adjusted model (M5) to include the interaction term between these measures and risky driving. Effect modification was assessed on the additive scale by calculating the relative excess risk due to interaction (RERI) (VanderWeele and Knol, 2014).

We estimated how many crashes could be avoided if measures were implemented to successfully reduce risky driving using the Global Burden of Disease study framework for comparative risk assessment calculating the population attributable fraction (Stanaway et al., 2018) This allows definition of counterfactual scenarios of reduction in risky driving and estimation of this on crashes. Two scenarios were defined: (1) All drivers have the same crash rate as those in the lowest risky driving group, (2) drivers with above average risky driving (4th and 5th quintile) have the same crash rate as the average in this cohort (3rd quintile).

$$PAF = \frac{\sum_{i=1}^{n} piRR_i - \sum_{i=1}^{n} p_i^{'}RR_i}{\sum_{i=1}^{n} p_i RR_i}$$

where pi is the proportion of the population exposed at exposure level i, p'i is the counterfactual exposure distribution and RRi is the relative risk from the regression analysis (Model 5) at exposure level i.

We carried out all statistical analyses using Stata15 (www.stata.com).

2.5. Ethics approval

This study was approved by the Aboriginal Health & Medical Research Council of NSW Ethics Committee and the NSW Population & Health Services Research Ethics Committee (Reference: HREC/16/CIPHS/9).

3. Results

The cohort comprised of 20,806 drivers aged 17–24 at the time of the baseline survey in 2003/04. Just over half of all participants were women (54.6%) and most were 17–19 years old (85.6%) and lived in metropolitan areas (74.3%). Compared with drivers of the lowest risk-taking group, a higher proportion of high risk-taking drivers were men, were aged 17 at the time of the baseline survey, spent less than one year on a learner licence, rated their driving ability as much better compared with other drivers, used drugs and cannabis more than two times per week, drank alcohol more often, engaged in self-harm and drove for 10 h or more per week (Table 1).

Among risky driving behaviours, the most commonly reported were driving with multiple passengers (47.6%), driving while listening to loud music (42.3%), and driving at 70 km/h in a 60-km/h zone (21.3%). Least common was driving without a seatbelt (0.4%) (Supplement Table 1). A much larger proportion of drivers in the highest quintile of risky driving behaviour reported engaging often or very often in each of the risky driving behaviours compared with all other groups (Supplement Table 2).

During the study period 4,249 (20.4%) participants were involved in a crash, and of these, 216 were hospitalised for crash related injuries and 11 died due to a car crash (Table 2). A total of 581 drivers (2.8%) were involved in a single vehicle crash, 992 (4.8%) crashed in wet conditions, 1,254 (6.0%) in darkness and 152 (0.7%) were involved in a head-on crash.

Drivers in the highest two risky driving categories had a higher probability of crash during the 13 years of follow-up compared with those with the lowest risky driving scores (Fig. 1). After adjusting for all variables in the multivariable analysis (Model 5), drivers in the third (RR 1.16, 95% CI 1.05–1.30), fourth (RR1.22, 95% CI1.09–1.36) and fifth quintile (RR 1.36, 95% CI 1.21–1.53) had higher crash rates compared to the lowest risk-takers (Table 3). Drivers in the highest risky driving quintile had 1.92 (95% CI 1.13–3.27), 1.35 (95% CI 1.05–1.73), 1.55 (95% CI 1.25–1.93, and 2.14 (95% CI 1.07–4.28) times higher rates of crash related hospital admission or death, crashes in wet conditions, crashes in darkness and head-on crashes, respectively, compared with drivers of the lowest risky driving group.

Adding factors associated with crash (Model 2–5) to the model adjusted for demographics and driving exposure (Model 1) only had a small effect on differences in crash rates between high and low risk drivers.

After adjusting for all available covariates, there were positive interactions on the addtive scale between risky driving (quintile of most risky drivers) and self-harm for any crash and single vehicle crashes and risky driving and cannabis use (2–3 or 4plus per week) and crashes in the darkness (Supplement Table 6).

Estimation of how many crashes could have been avoided if measures successfully reduced risky driving in this cohort showed that 14.3% of all crashes and 33.2% of crash related hospital admissions could have been avoided in this cohort, respectively, if all drivers had the same crash rates as those in the lowest risky driving quintile. If drivers of the highest two risky driving quintiles had the same crash rates as drivers of the third (middle) quintile, 4.4% of all crashes and 8.8% of crash related hospital admissions could have been avoided in this cohort, respectively.

4. Discussion

To our knowledge this is the first study to show that drivers who report high levels of risky driving behaviour during adolescence remain at increased risk of car crash up to 13 years later. Adjusting for established crash risk factors reduced the differences in crash between drivers in the highest and lowest risky driving groups, but substantial differences remained.

For involvement in any car crash, we observed increasing crash risk with increasing risky driving behaviour. For crashes requiring hospital admission, head-on crashes and crashes in wet and dark driving conditions drivers in the highest risky driving group had a higher rates of crash compared with those in the lowest risky driving group, respectively. We observed no differences for single vehicle crashes between drivers in the highest and lowest risky driving groups. Drivers in the highest risky driving group who reported self-harm and frequent cannabis use were at increased risk of crash, compared with those who only reported one of these behaviours.

Our findings build and expand on those of the previous analysis of the DRIVE study on risky driving and crashes during the first two years of driving after obtaining a licence (Ivers et al., 2009). In the previous analysis we showed that drivers in the highest tertile of risky driving scores had 1.5 times higher risk of crash compared to those with the lowest scores (Ivers et al., 2009). In the current analysis we were able to show that differences in crash risk remained during the 13 year follow up and were even larger for crashes requiring hospital admission and head-on crashes. Moreover, the longer follow-up time and subsequently larger number of crash events allowed more nuanced analysis of risky driving behaviour as well as analysis of different crash outcome measures. Of note is the markedly increased risk of crashes resulting in hospital admissions and head-on crashes, both of which represent serious crashes. The increased risk of crash was sustained for all crash outcomes investigated, except single vehicle crashes, after adjusting for other established crash risk factors. This suggests that there is an important effect of behaviour over and above other measured determinants of crash.

We estimated that up to 14% of all crashes and 33% of hospitalised crashes could have been avoided if measures were implemented to successfully reduce risky driving behaviours. Extrapolating these findings to NSW population level suggest that measure that reduce risky driving could substantially reduce road crashes, potentially avoiding more than 3000 crashes resulting in injury requiring hospital admission each year (Transport for NSW, Centre for Road Safety, 2020) and thus make a significant contribution towards achieving national road safety goals.

However, to mitigate crashes in people who report risky driving

Table 2
Number of drivers with crash by risk-taking quintile. The DRIVE study, NSW, Australia 2003–2016.

		Lowest	Second quintile	Third quintile	Fourth quintile	Highest	Missing	Total
Type of crash		Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)
Any crash	None	3288 (83.1)	3206 (81.1)	3168 (80.1)	3112 (78.7)	2975 (75.2)	808 (78.4)	16,557 (79.6)
	1	562 (14.2)	649 (16.4)	676 (17.1)	718 (18.2)	802 (20.3)	189 (18.3)	3596 (17.3)
	2 or more	105 (2.7)	100 (2.5)	111 (2.8)	125 (3.2)	178 (4.5)	34 (3.3)	653 (3.1)
Crash related hospital admission or death	None	3922 (99.2)	3908 (98.8)	3914 (99.0)	3909 (98.8)	3905 (98.7)	1021 (99.0)	20,579 (98.9)
	1 or more	33 (0.8)	47 (1.2)	41 (1.0)	46 (1.2)	50 (1.3)	10 (1.0)	227 (1.1)
Single vehicle crash	None	3868 (97.8)	3877 (98.0)	3844 (97.2)	3832 (96.9)	3807 (96.3)	997 (96.7)	20,225 (97.2)
	1 or more	87 (2.2)	78 (2.0)	111 (2.8)	123 (3.1)	148 (3.7)	34 (3.3)	581 (2.8)
Crash in wet	None	3808 (96.3)	3771 (95.4)	3771 (95.4)	3759 (95.0)	3731 (94.3)	974 (94.5)	19,814 (95.2)
	1 or more	147 (3.7)	184 (4.7)	184 (4.7)	196 (5.0)	224 (5.7)	57 (5.5)	992 (4.8)
Crash in dark	None	3775 (95.5)	3749 (94.8)	3728 (94.3)	3708 (93.8)	3622 (91.6)	970 (94.1)	19,552 (94.0)
	1 or more	180 (4.6)	206 (5.2)	227 (5.7)	247 (6.3)	333 (8.4)	61 (5.9)	1254 (6.0)
Head-on crash	None	3939 (99.6)	3927 (99.3)	3928 (99.3)	3926 (99.3)	3912 (98.9)	1022 (99.1)	20,654 (99.3)
	1 or more	16 (0.4)	28 (0.7)	27 (0.7)	29 (0.7)	43 (1.1)	9 (0.9)	152 (0.7)

Table 3
Rate ratios# of crash by risky driving quintile, DRIVE cohort 2003–2016.

Crash	Model	Lowest	Second quintile	Third quintile	Fourth quintile	Highest
Any crash	M1 confounding	1	1.07 (0.97–1.19)	1.13 (1.02–1.26)	1.19 (1.07–1.31)	1.35 (1.22–1.49)
	M2 confounding & drugs& self-harm	1	1.07 (0.96–1.18)	1.13 (1.02–1.25)	1.17 (1.06–1.30)	1.31 (1.19–1.46)
	M3 confounding & risk perception	1	1.09 (0.98–1.21)	1.17 (1.05–1.30)	1.23 (1.10–1.37)	1.41 (1.26–1.58)
	M4 confounding & training & experience	1	1.08 (0.97–1.19)	1.14 (1.03–1.26)	1.19 (1.07–1.31)	1.33 (1.21–1.47)
	M5 confounding & drugs & training & experience	1	1.09 (0.98–1.21)	1.16 (1.05–1.30)	1.22 (1.09–1.36)	1.36 (1.21–1.53)
	M1 confounding	1	1.49 (0.95–2.34)	1.38 (0.87–2.20)	1.54 (0.98–2.43)	1.85 (1.17–2.90)
	M2 confounding & drugs& self-harm	1	1.48 (0.94–2.32)	1.37 (0.85–2.19)	1.50 (0.94–2.38)	1.74 (1.09–2.79)
	M3 confounding & risk perception	1	1.53 (0.97–2.42)	1.45 (0.90–2.32)	1.65 (1.00–2.72)	2.03 (1.21–3.40)
	M4 confounding & training & experience	1	1.48 (0.95–2.32)	1.38 (0.87–2.19)	1.53 (0.97–2.40)	1.82 (1.16–2.85)
Crash resulting in hospital admission or deaths	M5 confounding & drugs & training & experience	1	1.51 (0.96–2.39)	1.44 (0.90–2.31)	1.61 (0.98–2.67)	1.92 (1.13–3.27)
Crash in wet	M1 confounding	1	1.20 (0.97–1.49)	1.18 (0.95–1.47)	1.21 (0.98–1.51)	1.32 (1.07–1.64)
	M2 confounding & drugs& self-harm	1	1.19 (0.96–1.48)	1.17 (0.94–1.46)	1.20 (0.96–1.49)	1.28 (1.02–1.60)
	M3 confounding & risk perception	1	1.23 (0.98–1.53)	1.22 (0.98–1.54)	1.28 (1.01–1.61)	1.41 (1.11–1.80)
	M4 confounding & training & experience	1	1.21 (0.97–1.50)	1.19 (0.96–1.47)	1.21 (0.98–1.51)	1.32 (1.06–1.63)
	M5 confounding & drugs & training & experience	1	1.22 (0.98–1.53)	1.22 (0.97–1.53)	1.25 (0.99–1.58)	1.35 (1.05–1.73)
Crash in dark	M1 confounding	1	1.10 (0.90–1.34)	1.15 (0.95–1.41)	1.21 (0.99–1.46)	1.52 (1.26–1.83)
	M2 confounding & drugs& self-harm	1	1.09 (0.89–1.33)	1.14 (0.93–1.39)	1.18 (0.97–1.43)	1.45 (1.20–1.76)
	M3 confounding & risk perception	1	1.11 (0.91–1.36)	1.19 (0.97–1.46)	1.27 (1.03–1.56)	1.63 (1.32–2.02)
	M4 confounding & training & experience	1	1.10 (0.90–1.34)	1.16 (0.95–1.41)	1.20 (0.99–1.46)	1.50 (1.24–1.81)
	M5 confounding & drugs & training & experience	1	1.11 (0.91–1.36)	1.18 (0.96–1.44)	1.24 (1.01–1.52)	1.55 (1.25–1.93)
Head-on crash	M1 confounding	1	1.55 (0.83–2.87)	1.43 (0.76–2.66)	1.50 (0.80–2.83)	2.15 (1.19–3.90)
	M2 confounding & drugs& self-harm	1	1.57 (0.85–2.93)	1.49 (0.80–2.76)	1.60 (0.85–3.01)	2.39 (1.30–4.41)
	M3 confounding & risk perception	1	1.50 (0.80–2.83)	1.35 (0.70–2.62)	1.39 (0.69–2.77)	1.92 (0.98–3.78)
	M4 confounding & training & experience	1	1.53 (0.82–2.85)	1.41 (0.75–2.64)	1.50 (0.80–2.82)	2.17 (1.20–3.93)
	M5 confounding & drugs & training & experience	1	1.52 (0.80–2.86)	1.39 (0.72–2.69)	1.46 (0.73–2.94)	2.14 (1.07–4.28)
Single vehicle crash	M1 confounding	1	0.84 (0.62–1.14)	1.14 (0.86–1.50)	1.20 (0.91–1.59)	1.31 (1.00–1.71)
	M2 confounding & drugs& self-harm	1	0.83 (0.61–1.13)	1.10 (0.84–1.46)	1.15 (0.87–1.52)	1.19 (0.90–1.58)
	M3 confounding & risk perception	1	0.85 (0.62–1.16)	1.16 (0.87–1.55)	1.24 (0.92–1.67)	1.38 (1.01–1.87)
	M4 confounding & training & experience	1	0.85 (0.62–1.16)	1.15 (0.87–1.51)	1.21 (0.91–1.60)	1.31 (1.00–1.72)
	M5 confounding & drugs & training & experience	1	0.84 (0.62–1.15)	1.14 (0.85–1.52)	1.20 (0.89–1.62)	1.27 (0.92–1.75)

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 and 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 and average driving per week and risk perception score.
M4: age, sex, 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 driver training and time on learner licence.
M5: age, sex, socioeconomic status of area of residence (SEIFA index), remoteness of area of residence and average driving per week, cannabis smoking, alcohol consumption, drug use and self-harm, risk perception score, self-rated driving ability, number of attempts on driver test, crash before study, professional driver training and time on learner licence.

behaviours is not simple and more work is required that seeks to understand what drives risky driving and how this can be changed. We used a weighted index based on 13 measures of risky driving such as reckless driving, distraction, rule violation and aggression. Since the time of the baseline questionnaire in 2003/04 distraction through use of mobile phones and other electronic devices, is likely to have increased, this has been shown to be a key crash risk factor (Dingus et al., 2016; Scott-Parker and Oviedo-Trespalacios, 2017), Additionally more comprehensive tools to measure risky driving have been developed in the Australian context in recent years (Scott-Parker and Oviedo-Trespalacios, 2017; Scott-Parker et al., 2012). These might help in deriving more targeted information for injury prevention by distinguishing between different types of risky driving behaviours.

Evidence from longitudinal cohort studies has shown that persistent high-risk drivers were also more likely to engage in other forms of risk-taking and anti-social behaviours, suggesting that risky driving is likely to be a part of broader problem behaviours (Vassallo et al., 2013; Begg and Langley, 2004; Gulliver and Begg, 2007; Jessor, 2018). This is supported by our findings that high risk-taking drivers, more frequently consumed drugs and alcohol and self-harmed and that the combinations of risky-driving and self-harm and risky driving and cannabis use increased the risk of crash. These behaviours might be more prevalent in marginalised or underserved populations and campaigns that seek to prevent risk taking behaviours developed with such groups that also support them to address these co-occurring risk factors (Senserrick and Watson, 2021), may be effective in reducing risky driving.

Based on the evidence on the effectiveness of programs targeting drink driving (Freiburger and Sheeran, 2018), holistic early intervention programs, such as the Safe Streets Treatment Options Program (SSTOP) in Wisconsin, United States of America, which aims to keep offenders in the community and combine interventions such as supervision, education and treatment, might also be successful in reducing risk-taking behaviours and associated car crashes.

Additionally, brief interventions focussing on personal psychological risk factors integrated into driver training programs may be effective for improving traffic safety (Paaver et al., 2013). Beyond the individual level, wider system deterrence based campaigns that enforce speed limits, particularly at night, and in rural areas where head-on crashes are more frequent and road improvements to lessen the impact of poor driving choices can also contribute to reduced road trauma.

Our study also raises questions about the theorised stabilisation of risk behaviours at the end of adolescence (Patton et al., 2016). Adolescent risk taking has been explained by an imbalance in brain development during this life stage, with the area of the brain seeking heightened sensations and reward developing faster than the area that manages impulse control, known as the dual systems theory (Lambert et al., 2014; Casey et al., 2011; Lazuras et al., 2019). As young drivers mature the executive and social emotional systems become more balanced and risk-taking decreases. (Lambert et al., 2014; Casey et al., 2011; Lazuras et al., 2019) In the context of road safety, this is reflected in the successful introduction of graduated driver licensing systems which limit driving exposure of young drivers to known risky situations such as driving with peer passengers and driving at night (Williams, 2017). However, our results indicate that risky driving behaviours during adolescence may also be a marker of continued driving related risks that persist into adulthood. This is supported by findings of another Australian cohort study, which showed that risky driving remained stable in about two-thirds of study participants between ages 19–20 and 27–28 years, although follow up in the high risk driving group in this study was low (Vassallo et al., 2016). In the context of the dual systems theory this might indicate longer imbalance in brain development in some drivers compared to others.

Further, a much larger proportion of men compared with women reported to engage in risky driving in our study. This is in line with findings from previous studies (Cordellieri et al., 2016; Cestac et al., 2011) and suggests that gender specific measures to reduce risk-taking behaviours might have the potential to further reduce crashes. However, a growing body of evidence suggests that such problem behaviours have their origins in early childhood (Jessor, 2018; Vassallo et al., 2007; Spence, 2003; Twisk and Senserrick, 2021). Interventions at a younger age such as social skills training might offer one way of reducing risk-taking behaviours during adolescence and young adulthood (Spence, 2003). This is in line with a recently proposed life course approach to injury prevention, which includes an intergenerational temporal dimension and considers the wider social determinants of health (Hosking et al., 2011). Consequently, road injury prevention also needs to look past individual behaviour focussed interventions to account for the broader structural determinants of risky driving behaviours and crash related injuries such as family and community factors and education. For example, young drivers of low socioeconomic status might have older, less safe cars putting them at greater risk of crash and crash related injury (Metzger et al., 2020). This requires broader approaches to road transport injury prevention that extend beyond traditional ideas of safe systems interventions but instead address upstream structural determinants. Additionally, reducing driving exposure by increasing access to public or shared transport, local shops, services and schools and working from home as well as other measures that reduce traffic volume may also be a effective mitigation strategies (Twisk, 2000; May et al., 2008).

4.1. Strength and limitations

The strength of this study is its large sample size of over 20,000 participants, the rich information on potential confounders and the long follow-up of up to 13 years.

Some of the limitations are inherent to the use of routinely collected data and survey data relying on self-report. Crash data was derived from routinely collected NSW police, hospital and deaths data. Crashes that were not reported to police, did not require hospital admission or result in deaths or occurred outside of NSW were not covered in the analysis. We did not have information if the study participant was at fault. However, at fault' is commonly an excluded measure in young novice driver research given the potential for a skilled defensive driver to prevent a collision based on the fault of another road users. For example, the exemplar representative National Motor Vehicle Crash Causation Survey conducted by the US National Highway Traffic Safety Administration (U.S. Department of Transportation National Highway Traffic Safety Administration, 2008a; U.S. Department of Transportation National Highway Traffic Safety Administration, 2008b) codes both the critical pre-crash event and the critical reason for the crash. Based on analysis of critical reasons, it has been demonstrated that young driver errors are attributable to the vast majority of their crashes, irrespective of at-fault status (79%) (Curry et al., 2011).

Potential limitations around the DRIVE study sample have been discussed in detail elsewhere (Ivers et al., 2006). Participants in the DRIVE study were volunteers; as such, like other large cohort studies it was not a representative sample of the general population. Consequently, it can only provide reliable population estimates of the relative associations between risky driving and crash, but not absolute numbers or incidence rates.

Measures of risky driving and confounders were based on information from the baseline interview and we were not able to investigate changes in factors affecting risky driving and risky driving behaviour as drivers get older. Another limitation was potential bias in self-reported data, which could for example occur from recall bias or social desirable responding to interview questions (Paulhus, 1984; Chapman and Underwood, 2000). Moreover, the way the DRIVE study was set out, it only included licenced driver. Consequently, it was not possible to investigate crash in unlicenced drivers which are a particularly high risky driving group.

5. Conclusion

We showed that young drivers who reported to engage in risky driving when they first obtained their drivers licence remained at increased risk of crash past the initial period of driving well into adulthood. Measures that successfully reduce risky driving, especially targeting drivers in the highest risk-taking groups, have the potential to substantially reduce road crashes and transport related injuries and deaths. In addition to traditional enforcement-based approaches, systems wide approaches including strengthening of graduated licensing systems, and better management of driving exposure, and addressing the underlying wider social determinants of health are needed.

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Credit author statement

All authors contributed to the conceptualisation and design of the study. KR cleaned the linked data. HM led the analysis with input from KR and all other authors. HM and RI wrote the draft of the manuscript. All authors actively contributed to the interpretation of the findings and revision of the manuscript. RI, SB, TS and GP contributed to the design of the DRIVE cohort study and PC and KR to the relinkage of the DRIVE cohort.

Declaration of Competing Interest

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2021.106786.

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