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Accident Analysis and Prevention 36 (2004) 49–61

ACCIDENT ANALYSIS & PREVENTION

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The influence of alcohol, age and number of passengers on the night-time risk of driver fatal injury in New Zealand

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Received 2 May 2002; received in revised form 27 September 2002; accepted 12 October 2002

Abstract

Breath alcohol measurements and other data collected at randomly selected roadside sites were combined with data on fatally injured drivers in crashes occurring on the same weekdays and times (Friday and Saturday nights) at locations matched by the size of the nearest town. A logistic model was fitted to these data for the years 1995–2000 to estimate the effects of alcohol, driver's age and the influence of passengers carried on the risk of driver fatal injury in New Zealand. The estimated risks increased steeply with increasing blood alcohol concentration (BAC), closely following an exponential curve at levels below about 200 mg/dl (i.e. 0.2%) and increasing less than exponentially thereon. The model fitted to data for drivers under 200 mg/dl showed that risks at all BAC levels were statistically significantly higher for drivers aged under 20 (over five times) and for drivers aged 20–29 (three times) than for drivers aged 30 and over. Further, controlling for age and BAC level, driving with a single passenger was associated with approximately half the night-time risk of driver fatal injury relative to driving either solo or with two or more passengers. According to a recent travel survey, the types of passengers carried at the times of night and days of week studied appear to differ significantly from the types of passengers carried generally, which may lead to different passenger effects on driver behaviour. The high relative risk of teenage drivers means that they reach high risk levels commonly regarded as unacceptable in the field of road safety even at their current legal limit of 30 mg/dl, particularly when more than one passenger is carried in the car.
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Keywords: Alcohol; Risk; Case–control study; Passengers; Young drivers; Legal limit

1. Background

The relationship between alcohol consumption and the performance of tasks related to driving has been extensively studied in the laboratory. Such research has been motivated by the obvious road safety implications of alcohol impairment on the driving task and has been facilitated by convenient BAC measurements (particularly via breath samples). Moskowitz and Fiorentino (2000) conducted an extensive review of the literature on the effect of alcohol on driving-related skills and found that the majority of experimental studies reported significant impairment by a BAC of 50 mg/dl.[1] The studies they reviewed showed impairment due to alcohol in such behavioural areas as divided attention, drowsiness, vigilance, tracking, perception, visual functions, cognitive tasks, psychomotor skills and reaction time. There are relatively few case–control studies that have produced driver crash risk estimates by BAC. The most well known of these was conducted by Borkenstein et al. (1964) in Grand Rapids, Michigan, the data of which were analysed further by Allsop (1966) and Hurst et al. (1994). Borkenstein et al. compared the BAC of drivers involved in a random sample of all crashes in Grand Rapids with a control group of drivers selected from the city's traffic at the same locations and times as the crashes. It was found that the crash risk increased with increasing BAC, the risk curve steepening as higher alcohol levels were reached. Other studies, including McLean et al. (1980), Zador et al. (2000) and Maycock (1997), found steeply increasing risk curves with increasing BAC. The latter two of these made use of roadside survey data (collected at sites not determined by crash location) as a measure of exposure of drivers at various BAC levels combined with crash data that included information on driver BAC. There has been one published case–control study using New Zealand data: Keall et al. (2001) estimated the average proportional increase in risk per interval increase in driver BAC using a log-linear model fitted to data from a case–control study of fatally injured drivers matched with data collected from roadside breath-testing at randomly

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[1] The units of BAC used in this paper are mg/dl (or mg/100 ml); 50 mg/dl is equal to 0.05%.

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PII: S0001-4575(02)00114-8

selected sites. The proportional increase was larger for teenage drivers than for older drivers, for whom risks rose at a similar rate to that estimated by Maycock (1997), doubling for each 20 mg/dl increase. The New Zealand crash sample was dominated by single-vehicle crashes (64% of the sample), that have been shown by the studies cited above to be associated with steeper risk curves than multi-vehicle crashes. Further, the New Zealand road network is relatively unforgiving and may present relatively higher demands on drinking drivers than on sober ones, leading to steeper risk curves.

The effect of passengers on the crash risks of drivers has been quite widely investigated. Young drivers generally have increased crash risk when carrying passengers, but drivers aged 30 and over have a lower risk when carrying passengers (Chen et al., 2000). The age and gender of the passenger(s) also appear to influence crash risk. For example, a female passenger in a vehicle with a young male driver appears not to increase risk, whereas two or more female passengers does increase risk (Chen et al., 2000). There is supporting evidence that young passengers distract young drivers and even encourage them to take risks (Williams, 2000).

The analysis presented in this paper is based on models fitted to the same data analysed by Keall et al. (2001). The purpose was to investigate the influence of the carrying of passengers on driver risk and also to estimate driver risk by age and BAC level while controlling for any such passenger effects. A further aim was to estimate passenger effects on driver risk while controlling for the effects of alcohol and age for driving trips at a time of night and days of the week where the vast majority of travel in New Zealand is associated with socialising (Keall and Frith, 1997). These appear not to have been examined in the peer-reviewed literature to our knowledge. Finally, it was hoped to obtain good risk estimates at relatively low BAC levels, an area that had a relatively poor fit in the model described in Keall et al. (2001), which estimated the proportional increase in risk averaged over the entire available BAC range.

2. Methods

The case–control study used two principal data sources: control (or exposure) data from roadside breath-testing measurements and case data extracted from traffic crash reports for drivers killed in crashes, with BAC results from post-mortem reports. Data were also used from a national travel survey to estimate overall (crude) risk per driving trip and to describe aspects of travel behaviour during the times and days covered by the case–control data that may influence the risks estimated.

2.1. Control data: roadside breath-testing measurements

Data were used from 85,163 drivers who were breath tested at randomly selected inconspicuous roadside sites in 50 km/h speed limit areas between 1995 and 2000. In 1995 and 1996, the police stopped and directed vehicles to the roadside, where civilians breath tested and interviewed the drivers. Participation was voluntary for these 2 years only. From 1997 onwards, measurements were taken from compulsory breath-testing operations in which the police breath tested drivers. The information was gathered over late summer and autumn (February–May), on Friday and Saturday nights between 10:00 p.m. and 2:00 a.m. (the main drinking times). Three strata were defined according to the size of the population centre where each site was located. Information gathered included BAC (collected with virtually no non-response apart from 1995, when the response rate was 98.9%), age, gender, vehicle type and number of passengers. However, for 1996 and 1997, no information of the number of occupants of the vehicles stopped was recorded. Using data averaged over the remaining years, the proportions of vehicles with one, two, or three or more occupants within each cell cross-classified by the population size strata, driver age group and BAC class were estimated. These proportions, which were quite consistent over the years studied, were then used to impute the distribution of drivers aged 20 and over according to their passengers carried for the years 1996 and 1997 within these same cells.

The 1995 measurements covered about 57% of New Zealand's population, whereas the 1996 to 2000 measurements covered the entire country except areas more than 50 km from any population centre with at least 1000 inhabitants. The data were weighted to account for: variations in the proportions of passing traffic sampled; sampling probabilities applied to potential sites; the length of time information was gathered at each site; how many times a site was used in the given year (usually once or, rarely, twice). The average rural drivers' trip length was an estimated 50% longer than other drivers' trips, according to a household travel survey in 1997–1998 (described in Land Transport Safety Authority, 2000a). The rural driving trip involves more travel on higher speed limit roads that have a higher fatality risk per km driven. Thus, the exposure units do not provide a meaningful unit of comparison for risks of urban versus rural drivers. Further, sampling procedures and on-site procedures changed between years, leading to some variation in the number of sites that were inconspicuous (and hence useable). For these reasons, the control data were not used to compare exposure *between* strata defined by the year and the size of the population centre near where the data were gathered.[2] The vast majority of the control sample had BAC measurements derived from breath tests with a conversion factor of 2300 to convert breath alcohol to equivalent BAC (Walls and Brownlie, 1985). Only a small number of control drivers had evidential blood tests following their refusal of the breath test. Rarely (on less than five occasions), a driver who refused the breath test

[2] These stratification variables were conditioned out of the analysis (see Section 2.4).

would also refuse the blood test (resulting in prosecution). For these drivers, a low illegal BAC was imputed.

2.2. Case data: drivers killed

Data on fatally injured drivers were analysed from all crashes occurring between 9.30 p.m. and 2.30 a.m. on Friday and Saturday nights for the years 1995–2000 in the areas covered by the exposure data. The inclusion of the extra half-hours outside the periods covered by the exposure data (10:00 p.m. to 2:00 a.m.) was justified by the lack of certainty regarding the times of many night-time crashes. The BAC distribution of the dead drivers is unlikely to be much different for crashes that did occur during the extra half-hour periods. The crashes were also classified according to the size of the nearest population centre. Although control data were only collected on 50 km/h roads, data from a 1989–1990 travel survey[3] indicated that 92% of night-time trips made by non-main urban area drivers passed through urban speed limit areas that were within the scope of the exposure data collected. Therefore, crashes that occurred on 100 km/h roads close to sites where control data were potentially collected were considered to have appropriate exposure data and were included in the case sample. However, dead drivers of heavy vehicles and motorcycles were excluded because of their different characteristics vis-à-vis light four-wheeled vehicles: motorcyclists have about 18 times the risk of car drivers per hour driving (Land Transport Safety Authority, 2000b); truck drivers are much better protected and their driving task is very different.

Of the 103 dead drivers in the sample, only four were killed in crashes involving two vehicles whose drivers were both killed. Seventy-eight percent had BAC results available via postmortem tests and, of these, 70% were over the legal limit (for the age of the driver).[4] Police Officers attending the crash site record their judgement of each driver as “suspected” or “not suspected” of being impaired by alcohol. This judgement is recorded as “unknown” where the police officer has insufficient information. The police are generally quite accurate in this judgement: for all dead drivers in the years 1995–2000 where BAC results were available, 92% of drivers judged “not suspected” had a BAC = 0. Of those judged “suspected”, 77% had a BAC over 80 mg/dl. Such judgements made by US police officers have also been shown to be quite accurate (Grossman et al., 1996). The usefulness of this judgement made at the crash site is that it is made independently of the later decision whether to obtain postmortem BAC information from the driver, a decision that appears to be slightly biased towards the testing of alcohol impaired drivers. Given the accuracy of the Police judgement and the apparent bias towards non-testing of non-impaired dead drivers, it was decided to impute zero BAC for four drivers “not suspected” of being impaired who had missing BAC results. Following this imputation, 86% of the “not suspected” and “unknown” drivers had BAC results available, compared to 81% of the “suspected” drivers.

2.3. Travel survey data

The New Zealand Travel Survey 1997–1998 was a personal interview household-based national survey of travel with a sample size of 14,000 people. Data from this survey (which is described in detail in Land Transport Safety Authority, 2000a) include number of trips by travel mode, distance travelled per trip, time and duration of trip, etc. Information on age and gender of passengers carried by a given driver was only available for passengers who were members of the driver’s household (as they were also surveyed).

2.4. Data analysis

Two methods were used to estimate driver risk of fatal injury, a logistic regression model (see below) and crude risk ratios, defined as:

$$\frac{\text{risk}_j}{\text{risk}_0} \tag{1}$$

where $\text{risk}_j = a_j/c_j$, a_j is the count of dead drivers (from the *case* sample) and c_j is the estimate of exposure (weighted numbers of control drivers) for the driver-exposure[5] combination j. The denominator of (1) is the risk estimated for some baseline exposure category (with BAC = 0 in this study).

Although crude risk ratios have advantages over estimates from a statistical model in their simplicity of formulation, they make less efficient use of the available data than a well-fitted model. Furthermore, a model has the potential advantage of being able to estimate risk for specific groups of drivers or driving conditions while controlling for other factors. A conditional logistic model was therefore fitted to the data using the SAS procedure PHREG (SAS Institute, 1996). Terms corresponding to year, size of town and the intercept were “conditioned out” of the analysis (meaning that the variables were effectively controlled for, but no coefficients were estimated for them). To correctly fit the model for the situation where the control data were collected via a stratified random sample, a procedure due to Fears and Brown (1986) and discussed further by Hosmer and Lemeshow (2000) was applied. The use of standard logistic regression software to fit this model (as was done here) produces overestimates of the true standard errors. However, as the main stratum effects were already conditioned away, the Fears–Brown procedure

[3] The 1989–1990 travel survey (described in Land Transport Safety Authority, 2000a) was a national personal interview survey that collected detailed information on travel made by a sample of about 4000 people.

[4] The legal limits were 80 mg/dl for drivers 20 and over and 30 mg/dl for drivers under 20.

[5] A driver-exposure combination may be “trips made between midnight and 2:00 a.m. by teenage drivers”. The single index j is used for brevity to define groups cross-classified by driver type and exposure type.

amounted to a fine-tuning of the model and had little effect on the estimates. Although the model estimates the odds of fatal injury, the large size of the weighted control counts relative to the cases means that estimated odds are almost identical to estimated risks (Hosmer and Lemeshow, 2000, p. 50). Thus, throughout this paper, odds ratios are interpreted as risk ratios. The following explanatory variables and their interactions were available to be included in the model: BAC, driver gender, driver age (15–19, 20–24, 25–29 and 30+), "time of night" (before or after midnight), "number of passengers" (0, 1 and 2+). As their corresponding estimated coefficients were nearly identical, the age groups 25–29 and 20–24 were combined, which had negligible effect on the fit of the other parameters. With the objective of representing the observed data as parsimoniously as possible, only statistically significant terms were retained in the model. The model applied to the data was of the form:

$$\mathrm{logit}(\pi) = \sum_j \beta_j x_j \quad (2)$$

where π is the probability of driver fatal injury, x_j the jth explanatory variable and β_j the jth parameter (to be estimated from the data).

A natural model for counts (or proportions derived from counts) where the effects are independent is one where the effects are modelled multiplicatively (McCullagh and Nelder, 1989, p. 31), as in model (2) when both sides of the equation are exponentiated. The number of explanatory variables able to be included in the model needed to be restricted to ensure that reliable estimates of the parameters could be obtained. Peduzzi et al. (1996) suggested a rule-of-thumb that at least 10 events (here, dead drivers) should be available for each parameter estimated. Thus, for all models fitted, all possible explanatory variables could not be included simultaneously. At an early stage, it was apparent that BAC and age were the two strongest explanatory variables. Each of the other potential explanatory variables were then entered one at a time into a model with age and BAC to see whether any was statistically significant. Apart from age and BAC, only the variable "number of passengers" was found to be statistically significant at the 5% level in this form of model. A given dichotomous risk factor being entered into the model in the fashion described would have needed to have had an associated relative risk of 2 or more (or 0.5 or less) to be statistically significant.

3. Results

3.1. Crude and adjusted risk ratios

Table 1 shows crude risk ratios and adjusted risk ratios with 95% confidence intervals for all variables included in the final logistic model. Tables 2–5 show numbers of drivers by BAC interval and by factors "time of night", age, "passengers carried" and gender, with crude risk ratios by BAC (relative to zero BAC) for each driver group considered. The BAC "interval mid-points" are generally the middle of the respective BAC interval apart from the two lowest intervals ("<5" and "5–55") for which the average BACs of the drivers were approximately 0 and 17 mg/dl, respectively. The column headed "controls (n)" gives the raw sample numbers of controls surveyed; the column "weighted controls" gives the estimated number (in thousands) of driver trips on weekend nights during the study period for those areas of the country within the scope of the study (see above). As already described, the weights account for the sampling fractions applied to sites and passing traffic. A much higher sampling fraction was applied to sites in rural areas than in urban areas, meaning that there is some variation in the ratio (weighted controls)/(controls (n)). This variation was accounted for by the modelling procedure, however. The death rates per million trips are calculated by dividing the number of cases by the estimated (weighted) number of control drivers (trips). For those factors included in the final model, the adjusted risk ratios are shown, estimated at the value of the mid-point of the respective BAC interval, with 95% confidence intervals for the estimate in the subsequent column. As BAC was modelled as a continuous variable, the BAC intervals chosen are somewhat arbitrary in that they had no bearing on the modelling process. Note that the two highest BAC intervals have no adjusted risk ratios estimated as the model was restricted to BAC below 200 mg/dl.

The crude risk ratios shown in Table 2 suggest that there may be a steeper risk curve for drivers travelling in the 2 h after midnight than in the 2 h before. However, a term for the interaction between BAC and "time of night" in a model that included BAC, age and "time of night" failed to be statistically significant at the 5% level although there was suggestive evidence ($P < 0.1$) of more steeply increasing risks with increasing BAC after midnight. The overall male death rate is higher than the total female rate (last row of Table 5). Once again, a model that included gender provided only suggestive evidence of higher fatal injury risks for males ($P < 0.1$) per driving trip. Tables 2–5 show that within all available disaggregations of the data by BAC and another specified factor, there are steeply increasing crude

Table 1
Crude risk ratios and adjusted risk ratios with 95% confidence intervals estimated from final logistic model

Explanatory variable	Crude risk ratio	Adjusted risk ratio	95% CI
BAC (for 20 mg/dl increase)		2.01	(1.9, 2.2)
Age (relative to age 30+)			
15–19	2.15	5.25	(2.5, 11.1)
20–29	2.21	3.04	(1.7, 5.5)
30+	1.00	1.00	Reference level
Number of passengers (relative to 1)			
0	1.95	1.85	(0.9, 3.6)
1	1.00	1.00	Reference level
2+	1.93	2.25	(1.1, 4.7)

Table 2
Numbers of cases, controls and weighted controls by BAC interval and time of night, with crude risk ratios with respect to BAC

BAC interval (mg/dl)	Interval mid-point[a]	10 p.m. to 12:00 midnight					12:00 midnight to 2:00 a.m.					Overall				
		Controls (*n*)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio	Controls (*n*)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio	Controls (*n*)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio
<5	0	43,322	59,919	15	0.3	1.0	23,093	29,129	5	0.2	1.0	66,415	89,047	20	0.2	1.0
5–55	17	9,378	11,925	3	0.3	1.0	6,624	8,131	2	0.2	1.4	16,002	20,057	5	0.2	1.1
55–105	80	992	1,423	2	1.4	5.6	777	1,025	1	1.0	5.7	1,769	2,449	3	1.2	5.5
105–155	130	343	497	6	12.1	48.2	279	377	11	29.2	170.0	622	874	17	19.4	86.6
155–205	180	132	145	6	41.3	164.8	112	152	19	125.1	729.0	244	297	25	84.1	374.4
205–255	230	48	56	6	107.9	431.2	41	43	4	93.6	545.1	89	98	10	101.7	452.8
255–305	280	15	23	3	131.0	523.3	7	14	2	140.4	817.8	22	37	5	134.6	599.3
Total		54,230	73,989	41	0.55		30,933	38,871	44	1.13		85,163	112,860	85	0.75	

[a] Approximate average BAC of cases and controls in given BAC interval.

Table 3
Numbers of cases, controls and weighted controls by BAC interval and age group, with crude risk ratios and adjusted risk ratios with respect to BAC

BAC interval (mg/dl)	Interval mid-point[a]	Adjusted risk ratio	95% CI for adjusted risk ratio	Age 15–19					Age 20–29					Age 30+				
				Controls (*n*)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio	Controls (*n*)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio	Controls (*n*)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio
<5	0	1.0		10,363	11,986	5	0.4	1.0	20,424	28,944	7	0.2	1.0	35,227	47,343	8	0.2	1.0
5–55	17	1.8	(1.7, 1.9)	1,929	1,988	1	0.5	1.2	5,203	6,676	3	0.4	1.9	8,793	11,219	1	0.1	0.5
55–105	80	16.5	(12, 22)	136	154	0	–	–	562	765	3	3.9	16.2	1,048	1,475	0	–	–
105–155	130	95.0	(60, 151)	49	27	6	222.9	534.4	192	292	6	20.5	84.8	368	535	5	9.3	55.3
155–205	180	547.5	(287, 1044)	13	18	2	108.3	259.5	71	70	15	213.9	884.3	157	206	8	38.8	229.9
205–255	230	Not estimated		2	3	1	330.6	792.6	23	15	4	258.1	1,067.2	61	77	5	64.9	384.3
255–305	280	Not estimated		2	5	0	–	–	3	1	2	3319	13,722	17	32	3	94.5	559.3
Total				12,494	14,181	15	1.06		26,478	36,764	40	1.09		45,671	60,887	30	0.49	

[a] Approximate average BAC of cases and controls in given BAC interval.

Table 4
Numbers of cases, controls and weighted controls by BAC interval and number of passengers carried, with crude risk ratios and adjusted risk ratios with respect to BAC

BAC interval (mg/dl)	Interval mid-point[a]	Adjusted risk ratio	95% CI for adjusted risk ratio	No passenger					One passenger					Two or more passengers				
				Controls (n)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio	Controls (n)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio	Controls (n)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio
<5	0	1.0		27,797	37,706	7	0.2	1.0	23,995	33,059	4	0.1	1.0	14,572	18,231	9	0.5	1.0
5–55	17	1.8	(1.7, 1.9)	6,599	8,122	3	0.4	2.0	6,101	7,905	0	–	–	3,315	4,018	2	0.5	1.0
55–105	80	16.5	(12, 22)	757	1,127	3	2.7	14.3	605	814	0	–	–	378	471	0	–	–
105–155	130	95.0	(60, 151)	285	439	8	18.2	98.1	204	294	5	17.0	140.6	125	137	4	29.2	59.1
155–205	180	547.5	(287, 1044)	116	129	14	108.5	584.3	82	106	7	66.3	548.2	45	62	4	64.6	130.8
205–255	230	Not estimated		44	53	7	131.4	707.9	25	30	1	33.6	278.1	18	14	2	144.9	293.6
255–305	280	Not estimated		14	18	2	114.3	615.5	8	20	3	150.5	1244.2	0	0	0	–	–
Total				35,611	47,594	44	0.92		31,021	42,227	20	0.47		18,453	22,933	21	0.92	

[a] Approximate average BAC of cases and controls in given BAC interval.

risk ratios with increasing BAC. The sparseness of the case data at low positive BAC levels can be explained by the relatively low representation of such drivers on the road rather than by low risks at these levels.

Fig. 1 shows the distribution of cases (fatally injured drivers) and controls (driver trips estimated by random roadside breath-testing measurements) by BAC level. These are presented on a log scale to provide better resolution for the smaller percentages. The under-representation of the case sample (dead drivers) in comparison with the control sample at lower BAC levels and its overrepresentation at higher levels are clearly shown.

Fig. 2 shows crude risk ratios by BAC for each of three age groups separately, together with the model-based adjusted risk estimates (lines) as described below. It should be noted that the model-based estimates and the crude risk ratios are representing slightly different things: the model-based adjusted estimates control for number of passengers carried, year and location; the crude risk ratios are liable to be confounded by any of these factors, but nevertheless appear to be well-represented by the model-based estimates. For all three age groups, the crude risk ratios indicate that risk increases exponentially (appearing as a straight line against the log-scaled vertical axis) up to about 200 mg/dl, and then less than exponentially subsequently. Also apparent are the consistently higher risks for teenage drivers and drivers in their 20s than for drivers aged 30+. According to the estimates of the final model (see Table 1), teenagers have over five times the risk of drivers aged 30+ at all BAC levels modelled (less than 200 mg/dl) and drivers in their 20s have three times the risk of drivers aged 30+. When plotted on a logarithmic scale, parallel straight lines indicate that the risks per age group vary by multiplicative constants.

3.2. Checks on fit of the model

The usual goodness-of-fit statistics (the scaled deviance and Pearson's chi-square) could not be assumed to be reliably distributed according to the chi-square distribution, as the case data were sparse. The Hosmer–Lemeshow test could not be used to check overall goodness-of-fit as it is not valid for conditional models with sparse case data within strata. An informal examination of goodness-of-fit recommended by Hosmer and Lemeshow (2000) was carried out where observed and expected frequencies within various quantiles of risk were compared. For various divisions of the data into 10 quantiles, there was good agreement between fitted and observed totals. Three covariate patterns were identified by diagnostic plots as being unusual with respect to the fitted model; however, there was no evidence of errors in the data and they were not excluded from the analysis.

The impact of using imputed values for "number of passengers" for the control data of 1996 and 1997 was checked by repeating the fit of model excluding these 2 years. The estimated coefficients for the "number of passengers" terms were reduced by about a quarter, as

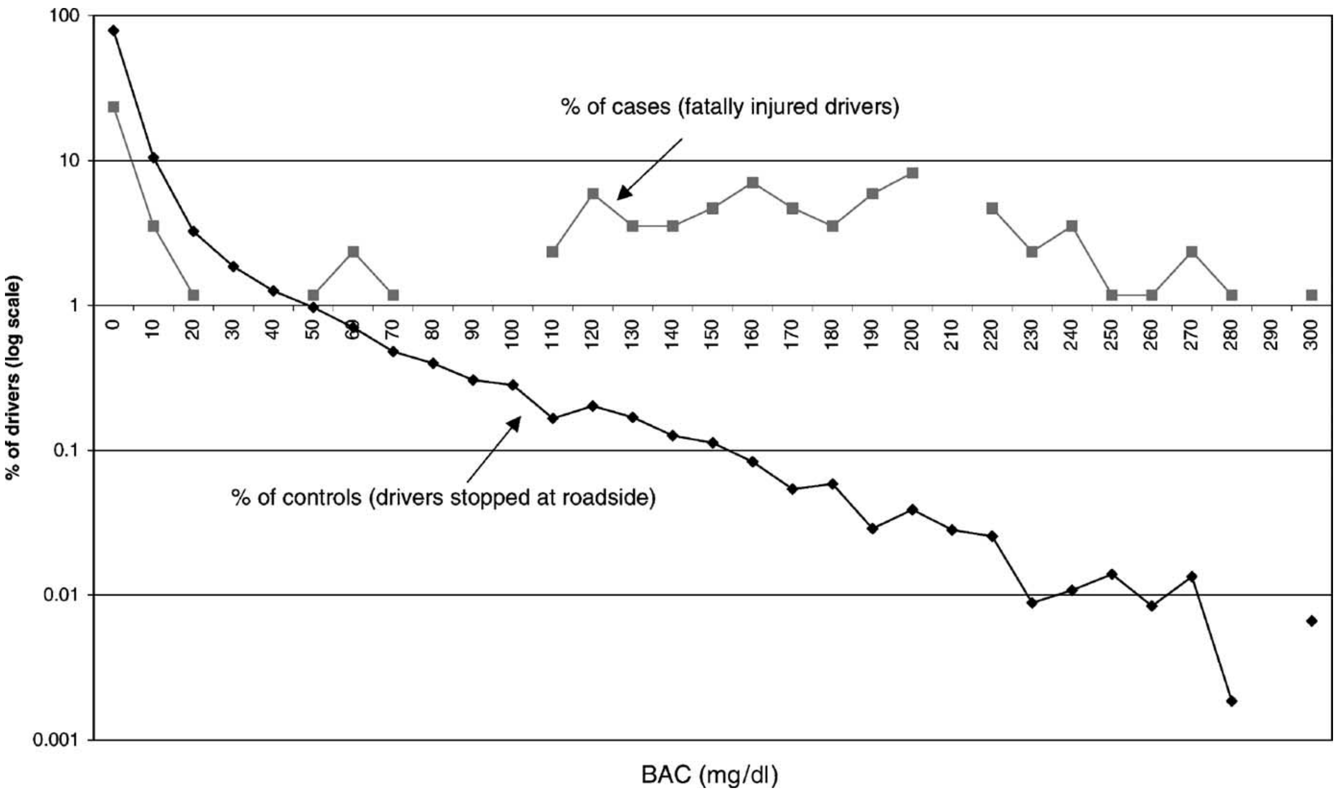

Fig. 1. Distribution of case and control data by BAC level.

Table 5
Numbers of cases, controls and weighted controls by BAC interval and gender, with crude risk ratios with respect to BAC

BAC interval (mg/dl)	Interval mid-point[a]	Females					Males				
		Controls (*n*)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio	Controls (*n*)	Weighted controls (in thousands)	Cases	Death rate per million trips	Crude risk ratio
<5	0	24,976	32,303	6	0.2	1.0	41,430	56,717	14	0.2	1.0
5–55	17	5,689	6,660	0	–	–	10,313	13,396	5	0.4	1.5
55–105	80	562	731	1	1.4	7.4	1,207	1,718	2	1.2	4.7
105–155	130	168	188	2	10.6	57.3	454	687	15	21.8	88.5
155–205	180	65	74	4	54.3	292.5	179	224	21	93.9	380.4
205–255	230	20	17	3	181.8	978.6	68	81	7	85.9	348.0
255–305	280	6	5	0	–	–	16	32	5	157.9	639.7
Total		31,486	39,977	16	0.40		53,667	72,855	69	0.95	

[a] Approximate average BAC of cases and controls in given BAC interval.

there were fewer data to counter the influence of the three covariate patterns identified above. As drivers on learner licences, who have restrictions on driving at night or with passengers, may have different risks from drivers on full licences, the model was also refitted firstly with interaction terms with age (as a surrogate for licence status) and secondly, excluding teenage drivers. The interaction terms were not significant, which may or may not be an artefact of the scarce case data for teenagers. As the estimates from the model that excluded teenagers were largely unchanged from those of the full model, there was no evidence of confounding associated with licence status. Models[6] were also fitted to the data that excluded 1996 and 1997 to assess potential confounding due to the variables “time of night” and gender (excluded from the final model because they were not statistically significant). The inclusion of these variables had negligible effect on the estimated coefficients

[6] Although the estimates from the models were of questionable validity (according to the guidelines of Peduzzi et al., 1996) because of the relatively large number of coefficients being estimated compared to the number of cases available.

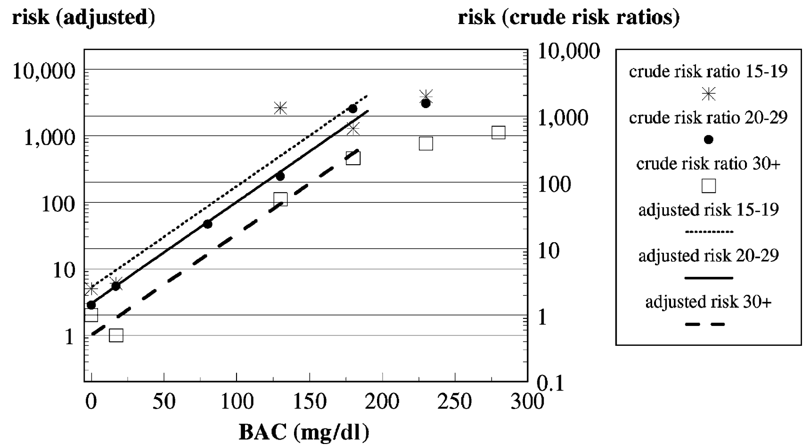

Fig. 2. Adjusted risk curves (with value defined by left-hand axis) and crude risk ratios (defined by right-hand axis) by age relative to sober drivers aged 30+.

of the final model, providing equivocal evidence that the exclusion of "time of night" and gender from the final model had not resulted in biased estimates.

3.3. Estimates provided by the model

Although a steeper teenage risk curve than for the older groups was found in the case of the average proportional increase estimated for these data in Keall et al. (2001), the current analysis (restricted to BAC under 200 mg/dl and controlling additionally for "number of passengers") did not. Nevertheless, as teenage drivers have a consistently higher risk (about five times that of drivers aged 30 and over, controlling for BAC and passengers carried), the multiplicative effect with the effects of BAC does generate a steeper risk curve in terms of absolute risk. For example, as shown on Table 6, at BAC = 0 and carrying a single passenger, teenage drivers have about five times the risk of such a driver aged

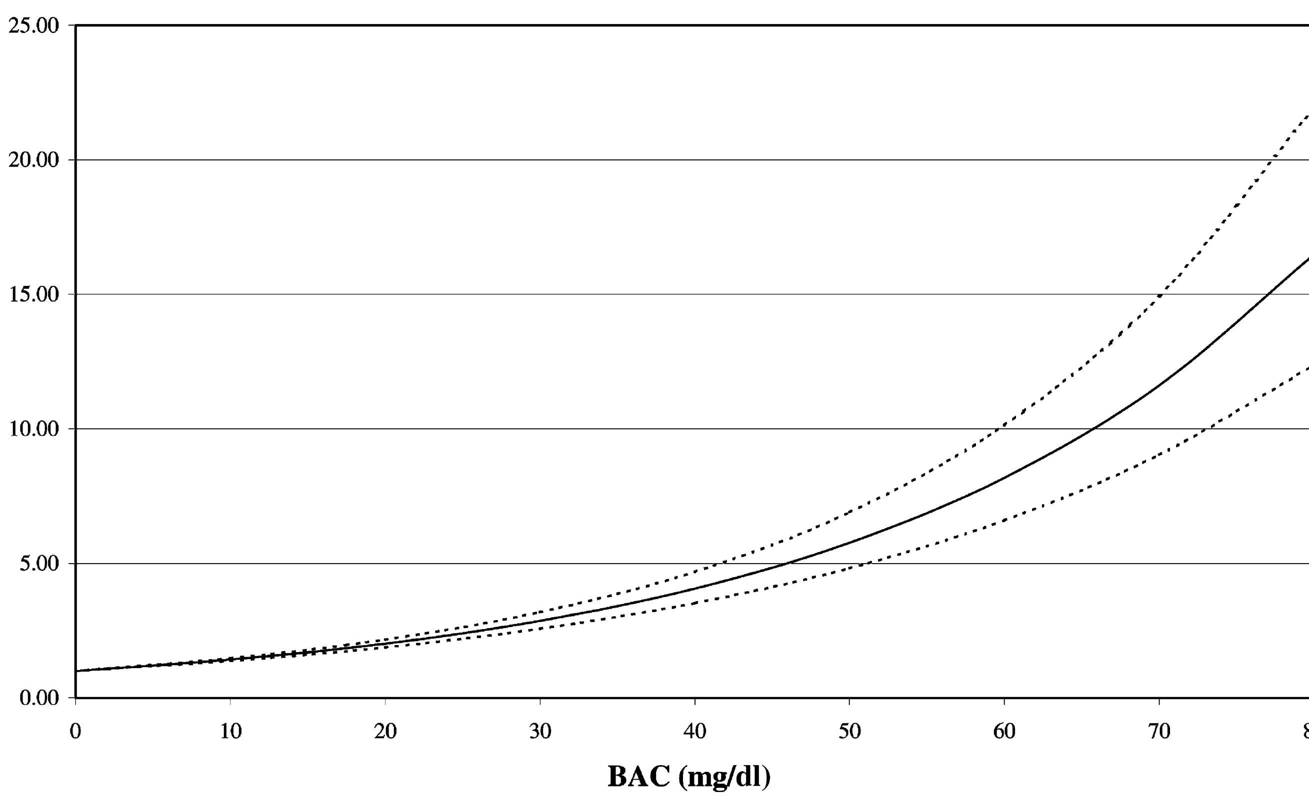

Fig. 3. Fatal injury risk (solid line) by BAC for any given driver group considered relative to that group's risk at BAC = 0 with 95% confidence intervals (dotted lines) on a linear scale.

Table 6
Adjusted risk (with 95% confidence intervals) by BAC (mg/dl), age group and passengers carried, relative to risk of sober driver aged 30+ with one passenger

BAC	Age 15–19			Age 20–29			Age 30+		
	No passenger	One passenger	Two or more passengers	No passenger	One passenger	Two or more passengers	No passenger	One passenger	Two or more passengers
0	9.7 (3.5, 26.8)	5.3 (2.5, 11.1)	11.8 (4.5, 31.5)	5.6 (2.3, 13.7)	3.0 (1.7, 5.5)	6.9 (2.8, 17.1)	1.8 (0.9, 3.6)	1.0 (Reference)	2.3 (1.1, 4.7)
30	27.7 (9.8, 78.3)	15.0 (6.9, 32.8)	33.9 (12.4, 92.3)	16.1 (6.5, 39.7)	8.7 (4.7, 16.1)	19.6 (7.8, 49.6)	5.3 (2.7, 10.3)	2.9 (2.6, 3.2)	6.4 (3.1, 13.6)
50	55.9 (19, 161)	30.3 (13, 68)	68.3 (25, 190)	32.4 (13, 81)	17.5 (9, 33)	39.6 (15, 102)	10.6 (5, 21)	5.8 (5, 7)	13.0 (6, 28)
80	159.9 (53, 479)	86.6 (36, 206)	195.2 (67, 567)	92.7 (36, 239)	50.2 (25, 100)	113.1 (43, 300)	30.4 (15, 62)	16.5 (12, 22)	37.2 (17, 82)
100	322.1 (104, 994)	174.5 (71, 432)	393.3 (131, 1182)	186.7 (71, 494)	101.1 (49, 209)	228.0 (84, 621)	61.3 (29, 129)	33.2 (23, 48)	74.9 (33, 170)

Table 7
Proportion (%) of driver trips with a fellow household member as one of the passengers by total number of passengers carried and period of night (1997–1998 Travel Survey)

Total number of passengers	Friday and Saturday nights		All times of day and days of week
	10:00–11:30 p.m.	11:30 p.m. to 2:00 a.m.	
1	63	65	70
2+	66	52	80

30 and over, and an *additional* risk of 4 (where 4 represents four times the risk of a non-drinking driver aged 30 and over with one passenger). At BAC = 30 mg/dl, teenagers have an additional risk of 12. For any given age group, risk doubles for every 20 mg/dl increase in driver BAC (see estimated coefficients in Table 1). The risks of teenagers relative to the sober risk of drivers aged 30+, therefore, also doubles with each 20 mg/dl increase, from just over 5 at BAC = 0 to over 10 at BAC = 20.

Fig. 3 shows on a linear scale model-based risk estimates relative to the risk at BAC = 0 for any given driver group as defined by the columns of Table 6, together with 95% confidence intervals (indicated by dotted lines) for the mean risk at each BAC level.

It appears that driving on weekend nights for all age groups and at all levels of BAC is least risky when a single passenger is carried (see Table 6). The assumption of multiplicativity of the risks that commonly applies for data of this type was supported by (a) the good fit of the model and (b) such graphs as Fig. 2 that show the risks for the three age groups as adequately represented by parallel straight lines on the logarithmic scale, indicating that the risks per age group vary by multiplicative constants. Given multiplicative effects, a teenager at a BAC of 30 mg/dl (the current legal limit for teenage drivers) carrying two or more passengers has a risk that is 34 times the risk of a sober driver aged 30+ driving with one passenger (see Table 6). The New Zealand current adult legal BAC limit of 80 mg/dl is associated with a risk that is 16.5 times the driver's sober risk for the given driver group. According to the final model (see the adjusted risks from Table 1), a driver aged between 20 and 29 with a BAC of 80 mg/dl carrying two or more passengers has an estimated risk calculated as follows:

$$\begin{aligned}\text{relative risk} &= (\text{risk associated with BAC})\\ &\quad \times (\text{risk associated with age})\\ &\quad \times (\text{risk associated with passengers})\\ &\approx 16.5 \times 3 \times 2.3\end{aligned}$$

So this driver group is legally driving at over 100 times (in fact, 113.1 times, according to Table 6) the risk of the safest driver group.

Table 7 shows that drivers travelling on Friday and Saturday nights who were carrying passengers were less likely to be carrying members of their own household than at other times of day and days of week. This was more particularly so when two or more passengers were being carried. Driver trips between 11:30 p.m. and 2:00 a.m. where two or more passengers were being carried were even less likely to include fellow household members as passengers.

4. Discussion

4.1. Estimates of risk at very high BAC levels

Fig. 2 shows that the fitted relationships between risk and BAC provide a good representation of the crude risk ratios by age group in the form of straight lines on the log-scale vertical axis against BAC under 200 mg/dl. Above this level, the crude risk ratios suggest a flattening in the rate of increasing risk. As this is consistent for all disaggregations of the data (see Tables 2–5), the departure from the dose response relationship evident for BACs under 200 mg/dl may indicate that there is a confounding influence from some other unmeasured factor above that level. No other study to our knowledge has had as extensive control data, particularly at high BAC levels, so this phenomenon may potentially be present in the data of other studies, but undiscovered due to more limited samples. A case–control study such as this one is often interpreted as though it were a dose response study in which the risk of the same individual is estimated for a range of BAC levels. Such a study could never be undertaken, and the inference that estimated risks at various BAC levels reflect an individual's change in risk must be made on the assumption that most of the important individual components of risk (for example, associated with age, gender, location, time of night and passengers carried) are accounted for in the model. Reasons for the departure at high BAC levels from the constant proportional increase in risk with increasing BAC can only be speculated upon. One possibility is that drivers at BACs over 200 mg/dl must have developed a reasonably high degree of tolerance to alcohol for them to undertake the rudimentary aspects of the driving task (even though their driving is at high risk of crash). Thus, this high-BAC group of drivers may be sufficiently alcohol-tolerant to initiate the driving trip but other less alcohol-tolerant individuals would not have been able to drive at such a high BAC. The risk ratios for BAC in the range 205–254.9 mg/dl for the three age groups considered range from 20 to 40% of the estimated risk extrapolated to higher BAC levels from the final model. By controlling for drivers' self-reported drinking frequency using a model fitted to the Grand Rapids data, Hurst et al. (1994) estimated that "daily" drinkers had 40% of the crash risk of "yearly or less" drinkers at all BAC levels investigated. However, they warned against interpreting such differences in risk as necessarily due to differences in alcohol tolerance of the driver groups being compared, as other demographic factors correlated to drinking frequency could easily influence risk to the same extent.

4.2. Risk associated with BAC

Previous studies of crash or casualty risk in relation to driver BAC level (Borkenstein et al., 1964; McLean et al., 1980; Zador et al., 2000) show more steeply increasing risk curves for more severe crashes, steeper curves for single-vehicle crashes than for multi-vehicle crashes, and steeper curves for driver fatality than driver fatal crash involvement. This last relationship may be associated with the increased vulnerability to trauma due to alcohol ingestion (see Evans and Frick, 1993). It is also possible that risks at night are higher due to a compounding of the effects of fatigue with those of alcohol (see Arnedt et al., 2001), supported in this study by weak evidence of more steeply increasing risks against BAC after midnight. Given these considerations, the crash sample used in this study could be expected to correspond to relatively steep risk curves. Possibly related to New Zealand's low levels of congestion (particularly late at night) and the grade of the road network, there was a high proportion of single-vehicle crashes (64% of the cases). The risks estimated here are higher (for equivalent age groups) than those estimated by Zador et al. (2000) for single-vehicle driver fatal injury; however, their sample was restricted to higher traffic flow roads and to larger population centres, which may have reduced their estimated risks relative to ours as lower grade roads may present relatively higher demands on drinking than sober drivers. For single-vehicle crashes, they estimated that every 20 mg/dl increase in BAC above 20 mg/dl increased risk of driver fatal injury by between 73% (drivers aged 35+) and 141% (teenage males). Our estimated increase in risk for each 20 mg/dl increase in BAC above BAC = 0 is 100% (a doubling of risk) for all driver groups. The estimated UK fatal driver injury risks of Maycock (1997) are similar to those presented here (for example, his estimated risk at BAC = 40 mg/dl is 3.7 for all drivers compared to our estimate of 4.0, with a 95% confidence interval that includes his 3.7). Keall et al. (2001) estimated a slightly lower rate of increase in risk with increasing BAC for the two older age groups (20–29 and 30+) and a higher rate for teenage drivers averaged over the entire available BAC range. The analysis presented here produced generally consistent estimates with this former study despite the inclusion of additional factors to control for "number of passengers", and other differences such as the use of conditional logistic regression (instead of the former Poisson log-linear model) and the restriction of the analysis to BAC less than 200 mg/dl. The case data for teenage drivers are probably too scarce to allow even relatively large differences in the exponent of the risk curve for teenagers compared to the older driver groups to be detected in the presence of the sort of random variation associated with small amounts of case data for teenagers, particularly when the effect of the number of car passengers is being controlled for. A steeper exponential risk curve for younger drivers than for older drivers was found in other case–control studies (e.g. Allsop, 1966; Zador et al., 2000) where the available data allowed such a disaggregation. In terms of the estimated risks per age group relative to drivers aged 30+, the estimates of 5.3 and 3.0 for the age groups 15–19 and 20–29, respectively (see Table 1), are consistent with the overall crude relative risk of involvement in injury crashes per driver trip at all times of day and days of week of 4.9 and 2.3 derived from New Zealand Travel Survey data combined with crash data.

4.3. Risk associated with passengers carried

Chen et al. (2000) considered that alcohol consumption by drivers (data that were not available for their study) was a potential confounder of the estimated risks for drivers carrying passengers. The present study has the strength that this highly influential factor is controlled for when estimating the effect of carrying passengers on driver risk. The principal weaknesses are that: (1) only a restricted (and very atypical) time period is being studied, meaning that the estimates are specific to that time period and are unlikely to apply to other times and days; (2) the restricted sample size for the subjects means that any interactions between the effects associated with age and passengers carried as identified by Chen et al. (2000) cannot be estimated. Nevertheless, there was no hint given by the data that such an interaction existed for the days and times of night studied. New Zealand's graduated licensing system limits the exposure of learner drivers to driving situations presumed to be at high risk for novice drivers for at least their first 18 months (normally longer) of driving before they are eligible for the full licence. One such restriction is that learner drivers are not allowed to carry passengers unless accompanied by a "supervisor" who is aged at least 20 and has been fully licensed for at least 2 years. This requirement is likely to affect risk related to the number of passengers carried, particularly for teenage drivers, who are more commonly learner drivers. For example, the risk of a learner driver who is breaching the conditions of the restricted licence by driving solo (i.e. without a supervisor) at night may be different from that of a fully licensed driver driving solo. In the sample of dead drivers, only 38% of the teenage drivers with known licence status were fully licensed; the proportions fully licensed in the 20–29 and 30+ age groups were 63 and 87%, respectively. No information on the licence status of drivers was collected for the control sample, meaning that matching of cases and controls by this variable was not possible. The limited number of teenage cases means that the estimated risk for teenagers carrying passengers must be interpreted with caution. It is the nature of the modelling procedure used that effects of one factor were assumed to be the same for each level of another factor unless there was strong enough evidence that an interaction existed. The scarcity of the case data restricted the statistical power to identify interactions unless their effects were large.

Most drivers travelling on Friday and Saturday nights (the subjects of the current study) are likely to have been socialising (Keall and Frith, 1997). Further, most passengers carried by drinking drivers would themselves have been drinking alcohol. Therefore, the presence of such passengers may act as a distraction to the driver (and the ability to deal with distractions is impaired with increasing BAC according to various studies: Moskowitz and Fiorentino, 2000). Although other research indicates that the presence of passengers overall has a beneficial influence on the safety of drivers aged 30 and over (Chen et al., 2000), the estimates provided by the current study show an increase in risk for such drivers (both when they are sober and with positive BAC) carrying two or more passengers. From this it may be inferred that on Friday and Saturday nights, the passenger–driver interactions may be different (and harmful from a safety point-of-view) compared to passenger–driver interactions at other times of the week. This difference may arise because of different relationships between drivers and passengers on Friday and Saturday nights, supported by estimates from the New Zealand Travel Survey showing that only 16% of passengers trips during weekend nights included passengers under 15 years, driven by a household member compared to 40% at other times of day and days of week. Table 7 shows that only about a half of late weekend night driver trips in which two or more passengers were carried included another household member, in contrast to 80% of such driver trips at all times of day. However, when a single passenger is carried on weekend nights, for almost two trips out of every three this passenger is a fellow household member. Thus the types of passengers carried appear to differ considerably for the study period (covered by the case–control data) from the types of passengers carried generally, particularly when two or more passengers are carried. It is likely that other household members (particularly if they are spouses or dependants) may have more of a moderating effect on driver behaviour than may friends and acquaintances, which may provided some explanation for the weekend night safety-beneficial effect of carrying a single passenger compared to the increased risk associated with carrying two or more passengers. The current analysis cannot shed light on specific passenger–driver dynamics; all that can be inferred is that—on average—carrying two or more passengers on weekend nights is associated with more than double the risk compared to driving with a single passenger (and that this effect is multiplicative, having a net larger impact on younger drivers and drivers who have consumed any alcohol) and driving solo is associated with an almost doubled risk relative to carrying a single passenger. It is common sense that drivers with passengers have the responsibility of the safety of their passengers and hence should take measures to minimise risk. The results of this study, which show that the relative risk of carrying two or more passengers is multiplied by the relative risk associated with alcohol consumption, emphasise that a driver should aim to be totally sober (not just under the legal limit) when carrying passengers. "Designated drivers" should have only non-alcoholic drinks. Even in the absence of any higher risk identified with the carriage of passengers, a driver trebles or quadruples the overall injury potential of a given crash by carrying two or three passengers as the passengers must also experience the forces involved in the crash. Of course, the risks estimated in this paper are for *driver* fatal injury; however, crashes that kill drivers normally involve impacts severe enough to cause considerable harm to other vehicle occupants, particularly if they are intoxicated.

Analysis of the control data collected from the random roadside breath measurements showed that for the two older driver groups in rural areas there was little difference between those at or below 30 mg/dl and those over 30 mg/dl in their proportions of trips with two or more passengers. However, there was a huge increase (from the low to the higher alcohol groups) for rural teenage drivers. This phenomenon appeared to be stable over the 4 years of control data studied. Teenage, drinking drivers who are carrying two or more passengers are the highest risk group identified by the model and must logically be a target of countermeasures to reduce this high-risk drink-driving behaviour.

4.4. Limitations and strengths

This is the first study (to our knowledge) to evaluate risk at high alcohol times by numbers of passengers carried, driver age and driver BAC. As these factors were all included in a statistical model, estimates of each of these effects on driver fatal injury risk could be made while controlling for the effects of the other factors. Further, this is the first case–control estimation of alcohol's effects on crash risk where the troublesome bias of risk estimates due to incomplete BAC data for control drivers can be virtually ignored because of the use of data from drivers required to provide breath or blood samples under New Zealand's Compulsory Breath-Testing legislation. The imputation of numbers of passengers carried within BAC/town size/age classes for the control data of the 2 years studied introduces some additional uncertainty for the estimates of risk by number of passengers carried. However, the stable proportions of drivers carrying given number of passengers within BAC/town size/age classes for the other years suggests that the imputation is quite reasonable. The main weakness of this study is the sparseness of the cases (dead drivers) for the time intervals studied. This has meant that some factors (in particular, gender and "time of night") and interactions of factors that were potentially influential on the risk estimated could not be included in the statistical model. As gender was found to be a significant variable in explaining driver fatal crash risk in Zador et al. (2000), it would have been desirable to have included gender in our model despite its lack of statistical significance. The weak evidence ($0.05 < P < 0.1$; found when gender was included in a model along with BAC and age) of a higher risk at all BAC levels for males than for females is consistent with crude risks of fatal injury per driving trip at all times of day estimated using New Zealand Travel Survey data combined with crash data. However, the scarcity of case data limited the final model to the variables BAC, age, and number of passengers carried. Imputation of zero BAC for three drivers who had missing BAC data is another source of uncertainty. If any of the drivers with imputed zeros in reality had non-zero BACs then our study would estimate slightly *lower* relative risk than those estimated from the complete data. The slightly higher rate of available BACs (following the imputation) for the "not suspected" and "unknown" group than the "suspected" group would also be expected to lead to marginally lower risk estimates.

5. Conclusions and policy implications

The New Zealand risk of driver fatal injury during the main drinking times increases steeply with increasing BAC, doubling for each 20 mg/dl increase in driver BAC. Teenage drivers are estimated to have more than five times the risk of drivers aged 30+ at all BAC levels. Drivers in their twenties are estimated to have three times the risk of drivers aged 30+ at all BAC levels. Further, controlling for age and BAC level, driving with a single passenger is associated with approximately half the night-time risk of driver fatal injury relative to driving either solo or with two or more passengers. The risk estimates presented here are generally higher than for other comparable studies in other countries, which may reflect the demands of road conditions in New Zealand as well as the nature of the crash sample used where almost two out of every three fatally injured drivers died in a single-vehicle crash.

There are several results that have obvious safety policy implications related to permitted alcohol levels as well as to public education. (1) A teenager at a BAC of 30 mg/dl (the current legal limit for teenage drivers) carrying two or more passengers has a risk that is 34 times the risk of a sober driver aged 30+ driving with one passenger. The high risk of young drivers relative to older drivers calls into question the level of the current legal BAC limit for young drivers. (2) Analysis of the control data has shown that on Friday and Saturday nights, teenage drinking drivers in rural areas tend to carry several passengers, a behaviour that is associated with very high risk. (3) The risk of drivers carrying two or more passengers rises very steeply even at modest BAC levels. This has implications for drivers with the responsibility of passengers at social events who restrict their drinking to legal levels but nevertheless impose elevated risks on themselves and their passengers. (4) A driver aged between 20 and 29 with a BAC of 80 mg/dl carrying two or more passengers is legally driving at over 100 times the risk of the safest driver group (sober drivers aged 30+ with one passenger).

Acknowledgements

The considered and constructive comments of two anonymous referees are gratefully acknowledged. This paper does not necessarily represent the views of the Land Transport Safety Authority.

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