



The effects of introducing or lowering legal per se blood alcohol limits for driving: an international review

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Abstract

In this review evidence on the impact of introducing or lowering legal blood alcohol limits on traffic safety measures is examined. There is substantial variability in the types and rigour of methods used to evaluate these legislative measures, and thus not surprisingly there is variability in the results observed. In most but not all cases where an evaluation of an introduced or lowered legal limit has been conducted, some beneficial effect on traffic safety measures has been reported. These effects are in some cases relatively small, and in other cases may be temporary. In some jurisdictions, lasting reductions in collision rates have been reported. Available evidence suggests that where beneficial effects are observed they are due to general deterrence, and not restricted only to drivers at blood alcohol concentrations (BAC) specifically affected by the legal change. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Legal measures have provided the foundation of modern efforts to reduce drinking-driving and the associated collisions, injuries and fatalities (e.g. Jonah and Wilson, 1983; Ross, 1984, 1991; Transportation Research Board, 1987; Homel, 1988; Surgeon General, 1989; Vingilis, 1990; Voas and Lacey, 1990). Zimring (1988) noted that with recognition of the large impact of drinking-driving laws on highway deaths and injuries, these laws and related issues became part of the public agenda and considerably more attention began to be paid to this issue. The key to efforts to reduce the

alcohol-crash problem in recent years has been the adoption of what has been termed the 'Scandinavian model' of deterrence of drunk driving. In this model, laws which make it an offence to drive with a blood alcohol level beyond a certain limit are implemented (Ross, 1973; Andenaes, 1984) and the offence results in such sanctions as licence suspensions and jail terms. These per se laws greatly facilitate the apprehension and prosecution of drinking drivers by providing an objective and simple means of detecting alcohol impairment.

The country credited with introducing the first per se law is Norway, which made it an offence to drive with a blood alcohol concentration (BAC) of 50 mg% in 1936 (Voas and Lacey, 1990). Without a per se law, the evidential basis for a conviction for a drinking-driving offence is behaviourally based. Behavioural observations of impairment are more ambiguous and can be easily challenged in courts. Per se laws enabled large

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scale and continuing attacks on drinking-driving based on general deterrence, and include major enforcement campaigns and public awareness efforts (Voas and Lacey, 1990). The level at which the legal limit allowed by the per se laws has been set over the years has depended on a variety of legal and political factors, in addition to evidence on the effects of alcohol on collision risk. Legal limits allowed by per se laws range from 20 to 150 mg%. Most countries have limits of 50 or 80 mg% (Mann et al., 1998).

In this review, the effects of introducing and reducing a legal limit will be examined. There are a variety of sources of information that are relevant to the question of what a legal limit should be. These include research on the effects of alcohol at various BACs on skills, attitudes and behaviours related to driving (e.g. Fillmore and Vogel-Sprott, 1996a,b), the effects on actual driving behaviour, and epidemiological investigations of collision risk (e.g. Holcomb, 1938; Lucas et al., 1955; Borkenstein et al., 1964; McCarroll and Haddon, 1964; Mayhew and Simpson, 1985; Vilardo, 1987; Zador, 1991). This information has been summarised in many authoritative reviews (e.g. Carpenter, 1962; Hurst, 1974; Simpson, 1985; Moskowitz and Robinson, 1988; Stamer, 1989; Howat et al., 1991; Vogel-Sprott, 1992; Krüger, 1993; Holloway, 1995; Koelega, 1995) and will not be discussed here.

The major purpose of this review is to summarise evidence on the impact of introducing or lowering the legal BAC on drinking-driving and associated collisions, injuries and fatalities. First, evidence from two substantive areas will be assessed — research on the effects of introducing a legal limit and research on the effects of lowering legal limits. The evidence considered will include information from official statistics (i.e. arrests, collisions, and fatalities) and data derived from roadside surveys. We will also consider what mechanisms might be operating in any instances where a beneficial impact of a reduced BAC is observed, for example whether any observed impact of a reduced legal BAC limit is specific to the group of drivers who drive at the BACs affected, or whether there is a more general impact of the measure on drinking-drivers. Additionally, we will consider what factors may operate to increase or decrease the effects observed when the legal limit is changed.

2. Effects of introducing a legal limit

Studies evaluating the impact of introducing per se laws are summarised in Table 1. These begin with Ross' (1973) evaluation of the British Road Safety Act of 1967, and have continued to recent times. This adoption of the 'Scandinavian model' marks the beginning of a wide international acceptance of this approach to preventing drinking-driving.

2.1. United Kingdom

Ross' (1973) examination of the impact of the British Road Safety Act, which introduced a legal limit of 80 mg%, is the pioneer example of the evaluation of a per se law. The law was introduced with great publicity in 1967. Ross' (1973) evaluation was additionally important because he used a time series approach to examine the impact of the measure. The initial impact of the law was dramatic. In the first 3 months after it was implemented, total traffic fatalities dropped by 23% and total injuries dropped by 11%. In the first year after the implementation of the law, the proportion of fatally injured drivers who were legally intoxicated (over 80 mg%) dropped from 32% of all fatally injured drivers to 20% (Transportation Research Board, 1987). These effects were even more pronounced on collisions that more frequently involve alcohol — nighttime and weekend collisions. In the months preceding the introduction of the law, there were about 1200 fatalities and serious injuries resulting from nighttime collisions each weekend. Immediately following the introduction of the law, this figure dropped precipitously to about 400. It then began to increase, and by 1970 it had returned to about 1000. Phillips et al. (1984), in a follow-up evaluation, considered whether or not the impact of the law had disappeared completely and concluded that there had been a significant and lasting (although small) impact of the British Road Safety Act on collisions, injuries and fatalities.

2.2. Canada

Canada introduced its per se law in 1969, making it a criminal offence to drive with a BAC over 80 mg%. The traffic safety impact of this law was examined by Carr et al. (1974) and by Chambers et al. (1974). Both groups of investigators found evidence of a modest impact. Carr et al. (1974) noted that, although it appeared that driving in the population was increasing (based on a rise in gasoline sales) total road fatalities declined by 6.3% in the year after the law's introduction. Nighttime fatal collisions declined from 29 to 27% of the total and weekend fatal collisions declined from 58 to 56% of the total. However, none of these changes were statistically significant, and additionally coroners' data on BAC levels among fatally injured drivers showed little change. Chambers et al. (1974) employed a regression analysis to estimate the impact on traffic fatalities, employing quarterly fatality rates between 1966 and 1971. They found a significant reduction in incidence of injuries from traffic collisions following the introduction of the law, with the largest decreases falling between 18:00 and 6:00 h when the highest proportion of drinking-drivers are on the road. Evaluation was hampered by problems with the data (e.g. lack

of comparability between provinces in collision reporting format). Some researchers concluded that the effect of the law was likely reduced by insufficient attention being paid to preparing police to using the new law to its maximal utility (Liban et al., 1987).

2.3. Japan

In 1970 a 0.5 mg% limit (essentially zero) was introduced in Japan. Deshapriya and Iwase (1996) noted that the proportion of fatal collisions involving alcohol had been increasing before the law was intro-

duced, and began to decline following the law's introduction. Between 1965 and 1970 the total number of people killed in traffic collisions increased from 12 484 to 16 765. However, by 1975 the number killed had fallen to 10 792. The authors also noted that over the same period alcohol consumption was increasing and the numbers of licensed drivers and registered motor vehicles was also increasing, and concluded that the law had the effect of reducing drinking-driving and alcohol-related collisions; however, no statistical tests were reported to support these conclusions.

Table 1
Summary of research evaluating the introduction of a legal BAC limit

Location	Authors	Measures	Design/analysis	Impact
United Kingdom, introduction of 80 mg% per se law in 1967	Ross (1973)	Various indicators of total and alcohol-related collisions	Time series analysis	Introduction of the per se law had a significant and in some instances dramatic impact which appeared to decrease over time
United Kingdom, introduction of 80 mg% per se law in 1967	Phillips et al. (1984)	Various indicators of total and alcohol-related collisions	Time series analysis	Analyses focused on whether there was any effect maintained over time (see above) and concluded that there was
Canada, introduction of 80 mg% per se law in 1969	Carr et al. (1974)	Various indicators of total and alcohol-related collisions; BAC levels of fatally injured drivers	Pre-post comparisons	Non-significant reductions in collision measures observed in the year after introduction; no changes in BAC levels of fatally injured drivers
Canada, introduction of 80 mg% per se law in 1969	Chambers et al. (1974)	Collision injury and fatality rates	Time series analysis	Significant reductions in injury rates; reductions in fatality rates marginally significant ($P = 0.11$)
Japan, introduction of 0.5 mg% per se law in 1970	Deshapriya and Iwase (1996)	Fatal collisions	Pre-post comparisons	Alcohol-related and total fatalities declined after the law was introduced—no statistical analysis reported
Netherlands, introduction of 50 mg% per se law in 1974	Noordzij (1977, 1994)	Roadside survey data, indicators of alcohol-involved and total collisions	Pre-post comparisons	Substantial reduction in numbers of drinking-drivers and alcohol-related fatalities; effects on total fatalities less clear
Netherlands, introduction of 50 mg% per se law in 1974	Van Ooijen (1977)	Alcohol-injury collisions	Pre-post comparisons	Immediate and substantial impact on alcohol-related collisions, some of which appeared to wear off with time
United States, introduction of 100 mg% per se laws in 41 states between 1975 and 1985	Zador et al. (1989)	Fatal collisions with varying probabilities of alcohol involvement	Time series analysis	Significant reductions in fatal collisions with a low and medium likelihood of alcohol involvement
United States, introduction of 100 mg% per se laws in states between 1982 and 1997	Voas et al. (2000)	Fatal collisions involving drinking-drivers with low BACs (10–90 mg%) and fatal collisions involving drivers with high BACs (100 mg% and above)	Weighted least squares regression analyses	Significant reductions in drivers with low BACs and with high BACs involved in fatal collisions

2.4. The Netherlands

The Netherlands introduced a legal per se BAC limit of 50 mg% in 1974. Noordzij (1977) reported the introduction of the 50 mg% limit was associated with a very pronounced reduction in the proportion of drivers who had a BAC of 50 mg% or above. According to Noordzij (1977), '... it can be stated that immediately after the change in the law on 1 November 1974, there were practically no drinking-drivers on weekend nights'. The impact on collisions was less clear. The number of fatal collisions involving alcohol declined substantially, but the effects of the 50 mg% limit could not be disentangled from other factors, such as the energy crisis of the early 1970s as well as the introduction of moped helmet legislation and seatbelt legislation. Van Ooijen (1977) also noted that there was an immediate and substantial impact on alcohol injury collisions, although this impact appeared to wear off over the year following implementation.

Noordzij (1994) also examined the long-term impact of the Netherlands 50 mg% law on drunk driving, using the series of roadside surveys. The proportion of weekend nighttime drivers with BACs over 50 mg% dropped from about 15% in the year preceding the law to less than 5% in the year following the law. The proportion of drinking-drivers increased the following year, but then there was a slow decline in the proportion of drivers who had been drinking. Noordzij (1994) commented that the introduction of the 50 mg% limit appeared to initiate a broad and sustained decline in the numbers of drinking-drivers in the Netherlands.

2.5. United States

Zador et al. (1989) evaluated the impact of a variety of legal initiatives, including introducing per se BAC laws, in American states between 1975 and 1985. Per se laws were introduced in 41 states during this time period. Their analysis revealed that introduction of per se laws was associated overall with a 2.4% reduction in total fatal crashes, but this impact was not statistically significant. The effect varied according to the estimated level of alcohol use by drivers. There were statistically significant reductions of 5.1% in collisions with a low probability of alcohol involvement and 8.6% in collisions with a moderate likelihood of alcohol involvement, but the impact on crashes with higher likelihood of alcohol involvement was not statistically significant. The probability of alcohol involvement was based on proportion of drivers killed with BACs at or above 100 mg% at various times of day. Collisions with a low probability of alcohol involvement were those that occurred between 6:00 and 15:59 h on weekdays and between 7:00 and 14:59 h on weekends (10–29% of drivers with a BAC at or above 100 mg%), and those

with a moderate likelihood of alcohol involvement were those which occurred between 4:00–5:59 and 16:00–18:59 h on weekdays and 6:00–6:59 and 15:00–17:59 h on weekends (30–49% of drivers with a BAC at or above 100 mg%).

Voas et al. (2000) utilised weighted least squares regression analyses to examine the impact of three legal measures (introducing legal limits, reducing the limit to 80 mg% and introducing Administrative Licence Revocation laws) using Fatality Analysis Reporting System (FARS) data from all 50 states plus DC from 1982 to 1997. All of the legal limits introduced were 100 mg% or more, and during that time examined they noted that the proportion of the US population covered by per se laws increased from 32 to 98%. In their analysis they were able to control for background variables including alcohol consumption (beer specifically), estimated miles travelled, unemployment rate and the passage of seatbelt laws. They observed a significant impact of introducing per se laws on alcohol-related fatal collisions. Per se laws were associated with an estimated reduction of 13.17% in numbers of low BAC drivers (BAC between 10 and 90 mg%) involved in fatal collisions, and a reduction of 8.69% in numbers of high BAC drivers (BAC greater than or equal to 100 mg%).

2.6. Summary

Several consistencies can be observed in these studies. Beneficial effects are usually reported when legal limits are introduced, although the magnitude of these effects varies considerably. For example, the impact of introducing an 80 mg% limit appeared to be much stronger in the UK than in Canada. As well, beneficial effects often appear to decrease over time, perhaps due to declining perceived risk of apprehension (Ross, 1973). This variability could depend on many factors, such as differences in the measures used (e.g. collision measures specific to alcohol vs. total collisions) and in the historical and social contexts of the countries involved. Differences in the methodologies used in these studies likely contributed to differences in findings. The range in methodological rigour is substantial, going from description of trends in a limited number of measures (e.g. Van Ooijen, 1977) to sophisticated and comprehensive regression and time series analyses (Ross, 1973; Voas et al., 2000). Many studies have been simple pre–post comparisons (e.g. Carr et al., 1974; Van Ooijen, 1977; Noordzij, 1977, 1994), and, therefore, subject to many potential sources of bias such as historical confounding and changes in broader social context (Campbell and Stanley, 1967). The strongest evidence for the impact of introducing a per se law is observed in studies employing the most rigorous designs and analytical procedures (Ross, 1973; Phillips et al., 1984; Zador et al., 1989; Voas et al., 2000).

3. Effects of reducing a legal limit

Reduced legal limits have been introduced and evaluated in parts of Canada, the United States, Australia and Europe. In the large majority of cases, the reduced limit introduced and evaluated is either 50 or 80 mg%. Evaluations of these initiatives are summarised in Table 2.

3.1. Canada

In 1981, the province of Ontario in Canada amended its Highway Traffic Act to introduce a 12-h roadside licence suspension for drivers who registered 50 mg% or more on a roadside screening device or evidentiary breath tester (Vingilis et al., 1988). The law was introduced December 17, 1981. In an evaluation of this law, Vingilis et al. (1988) tested a systems model of deterrence, where a successful deterrent effect of a new law required completion of several intermediate steps. These intermediate steps included publicity, education and enforcement which in turn generated increased knowledge and awareness of the law and increased perception of the risk of being caught if driving while drunk. Successful achievement of these conditions were hypothesised to result in a decrease in driving after drinking, followed by a reduction in alcohol-related fatalities. Vingilis et al. (1988) thus were particularly interested in these intermediate steps in the model. They noted that data on the intermediate steps suggested that many of the preconditions for a successful deterrent effect may not have been met, or were only partially met. For example, there was no organised public education campaign, media coverage was limited, and many police forces were not equipped to enforce the new law until a substantial length of time after it was introduced. Time series analyses were employed to examine the impact of the measure on the monthly log odds of motor vehicle fatalities having a positive BAC. Introduction of the measure suggested a significant reduction in alcohol-involved fatalities. Further confirmation of a beneficial effect specific to the introduction of the law was obtained from an analysis of a control time series from Saskatchewan and Manitoba in which no significant effects were observed. However, the impact appeared to be short-lived, and had largely disappeared after several months.

3.2. Australia

Several states in Australia have reduced their legal BAC limit to 50 mg%. Queensland lowered the legal limit from 80 to 50 mg% in 1983. The impact of this change was assessed by Smith (1986), who compared the BACs of collision-involved drivers in the years before and after the introduction of the law. Smith

(1986) observed significant reductions in the numbers of collision involved drivers who had been drinking. These reductions were higher at higher BACs (reduction of 12% at BACs above 150 mg%) than at lower BACs (reduction of 8% at BACs between 80 and 150 mg%).

In South Australia, the legal limit for all drivers was lowered from 80 to 50 mg% on July 1, 1991. Kloeden and McLean (1994) examined data from roadside breath alcohol surveys carried out in Adelaide, South Australia. These surveys were conducted using similar methodologies in 1991 (prior to introducing the 50 mg% limit), 1991 (following introduction of the 50 mg% limit) and 1993. The surveys focussed on late night driving (between 22:00 and 3:00 h). The numbers of drivers approached in each survey ranged between 6789 (1991 pretest) and 7841 (1993), and the refusal rate ranged from 5.3 (1991 pretest) to 4.5% (1993). A significant reduction in drinking and driving was observed in comparing the 1991 pretest to the 1991 posttest, and these reductions increased to the 1993 posttest. Overall, a decline of 14.1% in the proportion of drivers who were BAC positive from the 1991 pretest to the 1993 posttest was noted. This decline was more marked when the authors considered only the proportion of drivers who were over 50 mg% (reduction of 32.7%) and even more pronounced when they considered the proportion of drivers who were over 80 mg% (reduction of 38.2%). While these results are very encouraging, interpretation is limited by the various threats to validity of the simple pretest–posttest design (Campbell and Stanley, 1967). The authors note that interpretations of these data could not yet have been conclusive, because of the possible operation of other factors such as the introduction of random breath testing or general changes in social attitudes towards drinking-driving.

In a subsequent report, McLean et al. (1995) compared the roadside survey data to BACs of fatally injured drivers in the city of Adelaide. In this report, McLean et al. (1995) comment that the reduction in the percentage of late night drivers with high BACs appeared to be only temporary. They also noted that there appeared to have been a drop in the proportion of fatally injured drivers who had a BAC of 80 mg% or higher. It was difficult to specify if changes were due to the legislation because there appeared to be long-term trends in the measures. No statistical analyses were reported to support the authors' conclusions.

Brooks and Zaal (1993) evaluated the reduction of the legal limit in the Australian Capital Territory from 80 to 50 mg% on January 1, 1991. These authors examined several indicators of impact, including the recorded BACs of breath-tested drivers and crash-involved drivers. In comparing data from the year prior to the introduction of the law to data from the year following its introduction, BACs of tested drivers declined significantly. This effect became more pro-

Table 2
Summary of research evaluating a reduction of the legal BAC limit

Location	Authors	Measures	Design/analysis	Impact
Canada, introducing the 50 mg% 12-h suspension provision of the Ontario Highway Traffic Act in 1981	Vingilis et al. (1988)	Proportion of fatal collisions involving alcohol, plus various secondary measures of awareness, impact and enforcement of the law	Time series analysis	Introduction of the 50 mg% HTA provision had significant but apparently temporary impact on alcohol-related collisions, perhaps due to lack of awareness and enforcement
Australia, reduction of the legal limit in Queensland from 80 to 50 mg% in 1983	Smith (1986)	Collisions involving drinking-drivers	Pre–post comparisons	Reduction of the limit to 50 mg% resulted in a significant reduction in numbers of collision-involved drivers who had been drinking
Australia, reduction of the legal limit in the Australian Capital Territory from 80 to 50 mg% in 1991	Brooks and Zaal (1993)	Several indicators of drinking-driving and alcohol involvement in collisions	Pre–post comparisons	Reduction of the limit to 50 mg% resulted in a significant reduction in the BACs of collision-involved drivers who had been drinking, and in the BACs of drivers breath-tested by police
Australia, reduction of the legal limit from 80 to 50 mg% in 1991 in South Australia	Kloeden and McLean (1994)	Distribution of BACs among drivers in Adelaide	Pre–post comparisons	Reduction of the limit to 50 mg% resulted in a significant reduction in the BACs of drivers breath-tested in roadside surveys
Australia, reduction of the legal limit from 80 to 50 mg% in 1991 in South Australia	McLean et al. (1995)	Distribution of BACs in fatally-injured drivers and drivers tested in roadside surveys in Adelaide	Pre–post comparisons	Reduction of the limit to 50 mg% resulted in a temporary reduction in the BACs of nighttime drivers and a reduction in the proportion of fatally injured drivers with BACs over 80 mg% — no statistical analyses reported
Australia, reduction of the legal limit in New South Wales and Queensland from 80 to 50 mg% between 1982 and 1992	Henstridge et al. (1997)	Numbers of serious collisions, fatal collisions and single vehicle nighttime collisions	Time series analysis	Reduction of the limit to 50 mg% resulted in significant reductions in all collision and fatality measures in both states
United States, reduction of limit to 80 mg% in five states between 1983 and 1990	Johnson and Fell (1995)	Fatal collisions involving alcohol (six measures)	Pre–post comparisons	Significant reductions in nine of the 30 comparisons. Only one state (Maine) had no significant effects on any measure
United States, reduction of limit to 80 mg% in five states between 1983 and 1991	Hingson et al. (1996)	Fatal collisions involving alcohol	Pre–post comparisons, with matched control states	Significant reductions (16%) in proportion of collisions involving a driver with a BAC of 80 mg% or higher
United States, reduction of limit to 80 mg% in five states between 1983 and 1991	Scopatz (1998)	Fatal collisions involving alcohol	Pre–post comparisons, with matched control states	Significant reductions in proportion of collisions involving a driver with a BAC of 80 mg% or higher, but the magnitude varies depending on which states are used as comparisons
United States, reduction of limit to 80 mg% in North Carolina in 1993	Foss et al. (1999)	Various measures of alcohol involvement in collisions; BAC levels of fatally injured drivers	Multiple time series analysis with comparison states	Significant reductions in police-reported alcohol fatalities; no other significant effects observed

Table 2 (Continued)

Location	Authors	Measures	Design/analysis	Impact
United States, reduction of limit to 80 mg% in 11 states between 1983 and 1994	Apsler et al. (1999)	Various measures of fatal collisions involving alcohol	Multiple time series analysis	Significant reductions in alcohol-related fatalities in nine out of 33 analyses
United States, states that reduced the legal limit to 80 mg% by 1997	Voas et al. (2000)	Fatal collisions involving drinking-drivers with low BACs (10–90 mg%) and fatal collisions involving drivers with high BACs (100 mg% and above)	Weighted least-squares regression	Significant reductions in drivers with low BACs and with high BACs involved in fatal collisions
Sweden, reduction of the lower legal limit from 50 to 20 mg% in 1990	Norström and Laurell (1997)	Numbers of fatal collisions, single vehicle collisions and total collisions	Time series analysis	Reduction of the lower limit to 20 mg% resulted in significant reductions in all collision and fatality measures
Sweden, reduction of the upper legal limit from 150 to 100 mg% in 1994	Borschos (2000)	Number of fatal collisions and severe injury collisions	Time series analysis	Reduction of the upper limit to 100 mg% resulted in significant reductions in fatal collisions; the impact on severe injury collisions was similar but more variable
France, reduction of the legal limit from 80 to 50 mg% in 1996	Mercier-Guyon (1998)	Numbers of fatalities involving a drinking-driver in Haute-Savoie	Pre–post comparisons	Reduction of the limit to 50 mg% was associated with a decline in the numbers of fatalities involving a drinking-driver; no analyses reported
Denmark, reduction of the legal limit from 80 to 50 mg% in 1998	Bernhoft (2000)	Proportion of injury and fatal collisions classed as DUI	Pre–post comparisons	Reduction of the limit to 50 mg% was associated with a decline in the proportion of injury collisions and an increase in the proportion of fatal collisions classed as DUI; no analyses reported
Austria, reduction of the legal limit from 80 to 50 mg% in 1998	Bartl and Esberger (2000)	Proportion of collisions involving personal injuries classed as drunk driving	Pre–post comparisons	Reduction of the limit to 50 mg% was associated with a significant decline in alcohol involvement in personal injury collisions; statistical analyses not described

nounced as BAC levels increased; the declines among drivers with BACs below 150 mg% (–9 and –11% for drivers in the ranges 80–99 and 100–149 mg%, respectively) were not statistically significant, while the declines among drivers at higher BACs were highly significant (–34 and –59% for drivers in the ranges 150–199 and 200 and above, respectively). Additionally, the same pattern was observed among collision-involved drivers. These data suggest that the effects of this law were not restricted to drivers in the narrow BAC range affected, but instead exerted a very substantial effect for drivers at the highest BACs.

More recently, the impact of several drinking-driving countermeasures, including the introduction of 50 mg% limits, has been evaluated for the Australian states of New South Wales and Queensland (Henstridge et al., 1997). These authors applied rigorous time series methods to daily collision data (serious and fatal collisions) for time periods which began as early as 1976 and ranged up to 1992. The analyses controlled for seasonal effects, daily weather patterns, indices of economic and road use activity, alcohol consumption and day of the week. The authors examined the impact of these measures on all collisions, not just alcohol-related collisions, because of lack of consistent availability of BAC data. The results indicated a significant and apparently continued impact of the 50 mg% law. In New South Wales, the 50 mg% law was estimated to have reduced all serious collisions by 7%, fatal collisions by 8% and single-vehicle nighttime fatal collisions by 11%. Similarly, in Queensland the 50 mg% limit was estimated to reduce all serious collisions by 14% and fatal collisions by 18%. In these analyses the impact of other legislative initiatives, such as the introduction of Random Breath Testing, were statistically removed.

3.3. Sweden

Sweden has two BAC limits, a lower one for drunken driving and a higher one for aggravated drunken driving (Borschos, 2000). The lower legal limit was reduced from 50 to 20 mg% on July 1, 1990. Norström and Laurell (1997) (see also Norström, 1997) evaluated the impact of this change with rigorous time series analyses. Their time series data consisted of monthly data from July, 1987 to June, 1996, and included in their model were control series for alcohol consumption and miles driven. They observed significant reductions in fatal collisions, single vehicle collisions and all collisions of 9.7, 11 and 7.5%, respectively. They caution that the age distribution of drivers has changed somewhat, and estimate that this change could have accounted for about a third of the reduction in fatal collisions. This would reduce the impact on fatal collisions to about 6%. Norström and Laurell (1997) also examined the BAC distribution of convicted drinking-drivers in Swe-

den before (1987) and after (1991) the 20 mg% limit was introduced. They observed that the average BAC of those convicted declined significantly from 168 to 154 mg%. The distribution of BACs in this group appeared to shift, with a larger percentage being under 150 mg% and a smaller percentage being at 150 mg% and above. The largest reductions appeared at the highest BAC levels.

The limit for aggravated drunken driving was reduced from 150 to 100 mg% on February 1, 1994. Borschos (2000) evaluated this change with procedures similar to those reported by Norström (1997), Norström and Laurell (1997). ARIMA time series analyses utilising monthly data on fatal collisions and injury-producing collisions were conducted. Borschos (2000) also was able to control for the effects of alcohol sales and gasoline sales, and also incorporated the reduction of the lower limit in 1990 as a control variable. The results demonstrated a significant intervention effect of the 1994 law on fatal collisions, with reductions of about 13% being observed. The effects on severe injury collisions appeared somewhat more variable but in the same direction. The author notes that the 1994 law also introduced other changes including an increase in the maximum term of imprisonment for the aggravated drunken driving offence, and thus it is not possible to ascribe the traffic safety effects of the 1994 law exclusively to the reduced legal limit.

3.4. France

France reduced its legal limit from 80 to 50 mg% in 1996. Mercier-Guyon (1998) presented some preliminary pre–post comparisons on the impact of the 50 mg% limit in the French province of Haute-Savoie. He notes that there appeared to be reductions in alcohol-involved fatal and injury collisions following the introduction of the law. Specifically, total fatalities involving a drinking-driver declined from about 100 per year in the years preceding the introduction of the law (1993–1995) to 64 in 1997. However, the effect seems to have been delayed for unknown reasons or may have involved factors additional to the introduction of the 50 mg% limit, since the 1996 data (the first year of operation of the 50 mg% limit) seemed to be unaffected (111 deaths). Mercier-Guyon (1998) suggested that the impact of this measure was more pronounced for drivers at higher BACs (over 80 mg%) than for drivers in the 50–80 mg% range.

3.5. Denmark

Denmark reduced its per se limit from 80 to 50 mg% on March 1, 1998. Initial evidence on the effects of this change were presented by Bernhoft (2000). Survey data indicated that drivers reduced the amount of alcohol

consumed before driving with the new law, and that these reductions were attributed to the changed legal limit. Inspection of collision data suggested that while the proportion of injury collisions involving a drinking-driver (BAC of 50 mg% or more) appeared to decline with the introduction of the law, the proportion of fatal collisions involving a drinking-driver appeared to increase. The author comments that the follow-up period of 10 months may have been too short to assess the impact of legal change accurately. As well, no statistical analyses of the data are described.

3.6. *Austria*

Bartl and Esberger (2000) evaluated the reduction of the legal limit in Austria from 80 to 50 mg% in January, 1998. Data on police administered BAC tests indicated that the total number of tests administered had been increasing in the years before the law, and in the year after the law this increasing trend continued. There appeared to be declines in both the numbers of drivers with BACs over 80 mg% and the numbers of drivers with BACs between 50 and 80 mg%, although statistical tests were not reported. The absolute numbers of drunk driving collisions with personal injuries appeared to decline with the introduction of the law, while the total number of collisions with personal injuries appeared to increase. The proportion of collisions with personal injuries that were classified as drunk driving declined from 6.35 to 5.75%, and this decline was described as significant. However, the statistical analysis procedures and the methods for determining if a collision involved a drunk driver were not described.

3.7. *United States*

Several states within the US have reduced the legal per se limit to 80 mg% in recent years. Johnson and Fell (1995) examined the impact of lowering the legal limit to 80 mg% in five states which had the law in place for at least 2 years (California, Maine, Oregon, Utah and Vermont). These states had lowered the limit at varying times between 1983 and 1990. Utilising data from the FARS, they compared six indicators of alcohol-involved fatal crashes in the 2 years before versus the 2 years after the limits were lowered. The indicators involved all drivers aged 21 and over, and included fatalities that involved any alcohol, fatalities that were intoxicated (BAC > 100 mg%), police-reported alcohol involvement, single vehicle nighttime fatalities, single vehicle nighttime male driver fatalities, and estimated alcohol involvement (based on police reports, positive BAC tests, and recorded alcohol violations). Nine of the 30 pre–post comparisons revealed a statistically significant drop in alcohol involvement. Only one state (Maine) had no significant reductions in any indicator of alcohol-related fatalities.

Hingson et al. (1996) reported on the traffic safety impact of lowering the limit from 100 to 80 mg% in five states (Oregon, Utah, Maine, California and Washington) which took this step at varying times between 1983 and 1991. Hingson et al. (1996) matched each state with a neighbouring state that kept a 100 mg% limit over the same time period. The matching procedure was used to control for regional factors that might influence road safety (e.g. economic factors local to specific areas). Hingson et al. (1996) observed a significant reduction, across all states, in the proportion of crashes with a fatally injured driver who had a BAC of 80 mg% or higher. In comparison to states that maintained a legal limit of 100 mg%, those that introduced the 80 mg% limit experienced a reduction of 16% in the proportion of crashes involving a fatally injured driver whose BAC was 80 mg% or higher. This effect was not limited to drivers at the BACs affected by the law (i.e. those in the 80–100 mg% range). Instead, when Hingson et al. (1996) examined the proportion of drivers with higher BACs (150 mg% or higher), the reduction was even larger (18%). This observation suggests that reducing the legal limit by 20 to 80 mg% had a general deterrent effect which influenced drivers at all BAC levels. Some of this effect may have been due to other factors acting to reduce impaired driving, such as the introduction of Administrative Licence Revocation in some of the states over the time period examined.

Scopatz (1998) repeated some of the analyses carried out by Hingson et al. (1996) using different comparison states. He found that the overall reduction in the proportion of drivers over 80 mg% ranged from 14 to 4% (in comparison to Hingson et al. (1996) 16%). However, Hingson (1998) noted that Scopatz (1998) did not restrict comparison states to those that were geographically contiguous (e.g. in comparison that resulted in the lowest reduction in drinking-driving fatalities, Scopatz, 1998 compared California, a west coast state, to the three-state combination of Michigan, Ohio and Pennsylvania, all of which are eastern states).

Foss et al. (1999) examined the impact of the reduction of the legal limit to 80 mg% in North Carolina on October 1, 1993. The investigators employed several measures of alcohol involvement in collisions, including alcohol-related total, injury and fatal collisions based on a combination of police reported and medical examiner evidence, and surrogate measures of alcohol involvement (single vehicle nighttime crashes). Additionally, similar data from 11 states were aggregated for comparison purposes. Time series analyses revealed significant intervention effects only for police-reported measures of alcohol involvement in fatalities for North Carolina. Although there were general downward trends in alcohol-related collision measures, these were similar for all states and no evidence of an intervention effect was observed (with the exception of the

police-reported measure). As well, the investigators examined BACs of fatally injured drivers, and also found no evidence for a specific impact of the 80 mg% law. The investigators note that this apparent lack of effect of the new law might be related to several factors, including a true lack of impact, lack of public awareness of the law, and the state's history of vigorous enforcement of drinking-driving laws over the years.

In a multiple time series investigation, Apsler et al. (1999) examined the effects of introducing an 80 mg% limit in 11 states (California, Florida, Kansas, Maine, New Hampshire, New Mexico, North Carolina, Oregon, Utah, Vermont and Virginia) on fatal collisions involving drivers with a BAC over 10 mg%, those involving drivers with a BAC over 100 mg%, and the ratio of fatalities with BACs over 100 mg% to those with a 0 BAC. They observed significant intervention effects on at least one measure in five of the 11 states, and overall nine of the 33 analyses revealed a significant intervention effect.

Voas et al. (2000), as noted in the preceding section, also examined the impact of reducing the legal limit to 80 mg% in their evaluation of the effects of legal initiatives on drinking-driving fatalities in American states. They utilised weighted least squares regression analyses to examine the effects of several legal measures (including reducing the limit to 80 mg%) on low BAC (10–90 mg%) and high BAC (100 mg% or greater) driver fatalities derived from FARS data, for the 50 states plus DC from 1982 to 1997. The proportion of the US population covered by 80 mg% laws increased from 0 to 28% over that period. They found that 80 mg% laws were associated with significant reductions in drivers with both low and high BAC drivers involved in fatal collisions.

3.8. Summary

Table 2 summarises studies evaluating a reduction of the legal BAC limit. The characteristics of the research, and the experiences with this measure, appear to be very similar to those noted for evaluations of the introduction of legal limits. Due to the limitations involved in carrying out research on naturally occurring legal changes, each individual study reported here is subject to potential confounding factors. Those studies which report simple pre–post differences (e.g. Smith, 1986; Kloeden and McLean, 1994; McLean et al., 1995) are most subject to the confounding effects of such factors as simple historical trends, but even research employing sophisticated time series analyses, which can control for the effects of simple changes over time and other confounding factors such as alcohol consumed and general driving habits (e.g. Henstridge et al., 1997; Norström and Laurell, 1997), may under some circumstances be influenced by unidentified confounders.

Keeping this in mind, it appears that reductions in alcohol-related collisions, injuries and/or fatalities have been observed in most jurisdictions in which the legal limit has been reduced. Some variable findings emerge (cf. Kloeden and McLean, 1994; McLean et al., 1995; Bernhoft, 2000) which may be related to methodological differences between studies, as well as to differences in measures used and the specific social and historical context. In some cases, it appears that beneficial effects may decline over time (Vingilis et al., 1988; McLean et al., 1995), but lasting reductions in alcohol-related collisions and fatalities have also been reported (Henstridge et al., 1997; Norström and Laurell, 1997).

The American experience with reduced BACs is similar to that of other countries, and provides interesting illustrations of the range of results observed. Evidence for beneficial effects on road safety are observed in many of the states that have introduced an 80 mg% limit, but in some instances no effects have been observed (e.g. Foss et al., 1999). This variability could depend on the factors described earlier, including differences in public education and public awareness when the laws were changed and differing methodologies of the studies involved. It may also be important to consider that the BAC reductions involved in American studies have been relatively small (20 mg%). As well, per se laws differ in different states (NHTSA, 1997), and thus a change in the legal limit may well have different implications (and hence differing deterrent effects) in states depending on the legal structure. Thus, while the American experience with reduced legal limits so far appears to be positive in at least some instances, it is too soon to draw a final conclusion on what those effects are. A similar conclusion was reached in a recent review of the American experience with 80 mg% laws by the General Accounting Office (GAO, 1999). The GAO concluded that, although existing evidence does not conclusively demonstrate that an 80 mg% limit reduces alcohol-related collisions, there are strong indications that these laws, when combined with other legal measures, public education and vigorous enforcement, prevent alcohol-related collisions, injuries and fatalities.

This conclusion also appears generally consistent with the international literature. Although in most jurisdictions evidence for a positive impact on road safety is observed when legal limits are lowered, this has not always been the case. A lack of effect has been related to a follow-up interval that is too short (Bernhoft, 2000), and a reduced or truncated effect has been associated with a low level of public awareness and enforcement of the lower limit (Vingilis et al., 1988). Evidence for stronger effects on road safety are seen when other legal and public education initiatives are occurring which might serve to reinforce the effects of the lowered limit (Henstridge et al., 1997).

4. Who is influenced when legal BAC limits are changed

Epidemiological studies show that drivers in the lower BAC ranges, including those who would be affected when the legal limit has been lowered, constitute a relatively small proportion of impaired drivers and are responsible for a relatively small proportion of alcohol-related arrests, collisions, injuries and fatalities (e.g. Borkenstein et al., 1964; Anglin et al., 1997). It follows from the relative risk data that drivers at higher BACs, who are more likely to be involved in collisions than drivers at lower BACs, constitute a higher proportion of the drinking-driving problem. These high BAC drivers need to be a continuing focus of countermeasure efforts (e.g. Timken et al., 1995; Simpson et al., 1996). An important question to consider, then, is whether the impact of lowering a BAC is specific to drivers in the affected BAC range, or whether there is evidence of more general effects (general deterrence) on drivers at higher BAC levels.

Some of the research described above has addressed this issue. Most studies that have examined the impact of a lowered legal limit on measures of driver BACs, or BAC levels in arrested or fatally injured drivers, have observed a substantial impact on BAC levels other than those specifically affected by the change in limits. This effect has been observed when limits are reduced to 80 mg% (Transportation Research Board, 1987; Hingson et al., 1996) and when they are reduced to 50 mg% or lower (Brooks and Zaal, 1993; Kloeden and McLean, 1994; Norström and Laurell, 1997). The evidence currently available suggests that a reduction of the legal limit acts at all BACs, including the proportion of drivers with the highest BACs (e.g. 150 mg% or more), among those surveyed at the roadside, arrested, or fatally injured. However, one study (McLean et al., 1995) suggested that some of these effects wore off with time and one study (Foss et al., 1999) failed to observe any shift in BAC levels of fatally injured drivers when the limit was lowered.

These observations suggest that when an introduced or lowered legal limit exerts a beneficial effect on traffic safety, that effect is not restricted just to drivers at the BAC levels involved. Instead, the effect appears to be a result of a general deterrent effect on all drinking-drivers and the effects may appear to be strongest at the highest BAC levels. The recidivist, hardcore or high BAC driver has recently and deservedly been the focus of much concern (e.g. Mann et al., 1988b; Simpson and Mayhew, 1991; Timken et al., 1995; Macdonald and Mann, 1996; NHTSA and NIAAA, 1996), and these observations suggest that a reduced BAC limit may influence this group as well. However, the mechanisms for these effects when they are observed, and the reasons for failures to observe these effects, pose important challenges for future research.

5. Factors which influence the success of legal initiatives

The major impact desired with a new or reduced BAC limit is a general deterrent effect, where people who might otherwise drink and drive are deterred from doing so by knowledge of the law and the consequences of violating it (Homel, 1990; Vingilis, 1990). Previous studies have demonstrated that the introduction of new drinking-driving laws or policies can have a substantial general deterrent effect if they are introduced under certain conditions. The classic example is Ross (1973) analysis of the impact of the British Road Safety Act in 1969. He observed, initially, a significant and marked decline in collisions most influenced by alcohol (single vehicle nighttime collisions). However, the collision rate appeared to return to prelaw levels after about 1 year.

Various authors have suggested that this initial impact is due to an increase in perceived risk of being caught that is caused by the high level of publicity associated with new legal sanctions, while the subsequent reduction in impact is due to the realization that the actual risks of apprehension are not as high as initially believed (e.g. Ross, 1973; Vingilis and Salutin, 1980; Homel, 1990; Vingilis, 1990). Similar patterns of impact of new legal measures have been observed in Australia (Homel, 1990), and Ontario (Vingilis et al., 1988).

Homel (1990) argued that continued high publicity/public education efforts and high levels of enforcement by police will maintain the public's perceived risk of apprehension and thus result in a more pronounced deterrent effect of such laws. He evaluated this hypothesis in examining the effects of Random Breath Testing (RBT) in Australian states (Homel, 1990). In New South Wales, RBT was introduced under high impact conditions, i.e. with sustained public education and high profile enforcement efforts. Under these conditions, Homel (1990) reported that lasting collision reductions were observed; he estimated that alcohol-related collisions were reduced by 30% on what appeared to be a permanent basis. However, in other states RBT was not introduced with such intensity in either education or enforcement efforts, and similar sustained collision reductions were not observed (Homel, 1990).

As noted, although the impact of legal initiatives on collisions, injuries and fatalities can be positive, variability has been observed. This variability may result from differences in the public education measures surrounding the new laws. The general deterrent impact of new laws and other countermeasures appears to depend on the public's awareness of them as influenced by a variety of factors including the visibility with which they are enforced (Ross, 1973; Mercer, 1985; Homel, 1990; Vingilis, 1990; Vingilis and Salutin, 1980; Voas

and Lacey, 1990). In at least one previous instance, the evidence suggests that the collision-reducing potential of a new drinking-driving law was muted by low levels of public awareness (Vingilis et al., 1988). That is, in order for drivers to modify their behaviour, they must be made aware of the new law through public education and high-visibility enforcement.

6. Discussion

The impact of specific government policies usually must be examined under conditions that do not readily lend themselves to a rigorous experimental design. Laws and policies are often introduced by governments for political reasons, and evaluation of their impact is at best a secondary concern. As well, the results of individual studies must be treated with caution, because a variety of (often unknown) factors may be influencing the results. A specific confounding factor may cause an incorrect interpretation of a single study, while a variety of studies, carried out under different conditions, which lead to similar conclusions inspire greater confidence in the interpretation.

Legal measures are central to modern efforts to reduce the societal toll of injuries and fatalities which are the result of alcohol-involved collisions. The research reviewed here presents a promising but mixed picture of the traffic safety effects of introducing or lowering legal limits. In some instances few if any beneficial effects have been observed (e.g. Foss et al., 1999), in many instances there appears to have been at least a temporary reduction in alcohol-related collisions (e.g. Vingilis et al., 1988), and in other instances evidence for sustained benefits has been presented (Norström and Laurell, 1997). American research on the effects of lowering the legal limit from 100 to 80 mg% appears to be less conclusive than research from other jurisdictions. This may be related to the smaller reduction (20 mg%) involved in US evaluations than the 30 mg% reduction in most other jurisdictions evaluated (e.g. Vingilis et al., 1988; Henstridge et al., 1997). As well, in several instances, particularly in the US, evaluations of a lowered legal limit may have been partially confounded by other legal initiatives such as the introduction of administrative licence suspensions. Cultural factors may also contribute to observed differences between jurisdictions. For example, Scandinavian countries may have a more law-abiding culture which would favour the success of changes in the per se laws in comparison to jurisdictions with different cultural attitudes to the law.

A further point to keep in mind in evaluating this literature is that these changes have been implemented at a time when broad social changes in alcohol use and driving behaviour have been occurring. For example,

alcohol consumption levels in most Western jurisdictions stabilized and began to decline in the 1970s and 1980s, following many years of increases (Smart and Mann, 2000). Alcohol-related health problems, such as mortality rates from liver cirrhosis, have also been declining in Western countries in recent years. These declines frequently began before the declines in consumption, suggesting that factors influencing alcohol problem rates other than consumption levels have also been changing (e.g. Mann et al., 1988a, 1991; Holder and Parker, 1992; Smart and Mann, 2000). As well, collision rates have been demonstrating long term declines in Western countries. These broader social changes could be influencing at least some of the effects observed in some of the research described here. In efforts to control for these effects the more well-designed studies have included measures reflecting alcohol use and vehicle use (e.g. alcohol sales and gasoline sales in Norström and Laurell, 1997). Analyses incorporating these control measures allow for much stronger conclusions, even though the possibility that broader social factors are responsible for at least some of the changes observed can't be entirely ruled out. In general, research in this area would benefit from increased use of more sophisticated time series, multiple time series and cross sectional time series analytical models (e.g. Grunewald and Ponicki, 1995; Foss et al., 1999; Xie et al., 2000). Campbell and Stanley (1967) long ago noted that multiple time series designs can provide the same control over confounding factors as is provided in randomized trials.

An important consideration is the nature of the population affected by a change in the legal limit. As noted earlier, the proportion of drinking-driving collisions, injuries and fatalities caused by drivers at the specific BAC levels affected by changed legal limits is typically relatively small. However, research suggests that where there are positive effects of introducing or lowering a legal limit, those effects have not been limited to drivers in the affected BAC range. Instead, in the majority of studies where an effect is observed, an impact on all BAC levels is seen, suggesting a general deterrent effect.

Previous research identifies factors which will influence the observed effects of introducing or changing a per se law. To maximize the chances for a positive impact of such a measure, the public must be aware of the introduction of the law, perceive that it will be (or is being) enforced, and perceive that they have a strong chance of being apprehended if they break the law (e.g. Ross, 1973; Vingilis and Salutin, 1980; Homel, 1990). As well, police need the resources to carry out high visibility enforcement efforts (e.g. Jonah and Wilson, 1983; Jonah et al., 1999). Several levels of government may need to be involved for a new law to be effectively introduced and enforced. For example, in Canada the

federal Parliament creates provisions in the Criminal Code, but prosecution is the responsibility of the Attorneys General in each province and policing involves all levels of government (federal, provincial and municipal). Thus, the degree of support for a new or changed legal limit by each level of government involved is an important consideration.

The central purpose of this review was to determine whether or not the introduction or lowering of a legal BAC limit reduces alcohol-related collisions, injuries and deaths. In most jurisdictions in which a legal limit has been introduced or lowered, there is at least some evidence that these reductions have occurred. In addition, the broader context within which a new legal limit is introduced appears to influence any traffic safety benefits that might be observed, or possibly even whether any benefits are observed at all. Thus, these contextual factors, including levels of public and political support for the reduced BAC, are important determinants of the success of initiatives involving the legal limit, as is the willingness to introduce such a measure with the resources which appear necessary to achieve an impact on traffic safety.

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