THE ISSUE OF LOW BAC

BACs of U.S. Drivers in Fatal Crashes: Have They Changed in the Last 20 Years?

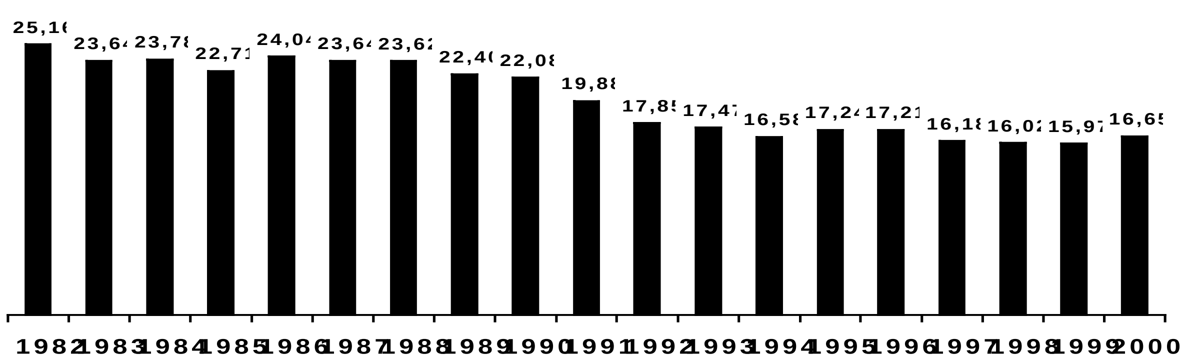
R. B. Voas and A. S. Tippetts

Pacific Institute for Research and Evaluation
11710 Beltsville Drive, Suite 300, Calverton, Maryland, 20705 USA

Keywords
Impaired driving, alcohol-related crashes, under-age drivers, female drivers, employment and crash involvement.

Abstract
The last two decades of the 20th century produced an explosion of alcohol-safety legislation and impaired-driving programs in the United States, in part stimulated by the growth in influence of citizen activist groups such as Mothers Against Drunk Driving. It was also encouraged by an unprecedented reduction in alcohol-related fatalities. As shown in Figure 1, between 1988 and 1994, alcohol-related fatalities in the U.S. fell from 23,626 to 16,580. However, six years later in the year 2000, there were 16,653 alcohol related fatalities (1). What happened? Why was the 30% drop over the six years prior to 1994 followed by a six year period of no reduction? This issue is coming to head this year because, in 1995, based on the dramatic reduction in alcohol-related fatalities occurring over the previous decade, the National Highway Traffic Safety Administration (NHTSA) led a national effort to organize industry and safety groups into a "Partners for Progress" organization devoted to reducing impaired driving in the U.S. That organization adopted a goal of reducing national alcohol-related fatalities to 11,000 by 2005. The failure to make any progress toward that goal since 1994 requires a new goal to be set for the coming decade. But, more important, it is raising the question of which laws and programs can restore the downward trend in alcohol-related fatalities. This paper examines the trend in fatal crash involvements from 1982 to 1999 to shed some light on the factors that may have influenced the initial reduction of alcohol-related fatalities.

Figure 1: Alcohol-related traffic fatalities from 1982-2000



Introduction

The U.S. Fatality Analysis Reporting System (FARS) provides a basis for beginning an analysis of this recent trend. It contains a relatively high proportion of cases for which the driver's blood alcohol concentration (BAC) is available. Overall, BACs are available for 70% of the fatally injured drivers and 24% for those who survive fatal crashes. These data are extended by an imputation process (2) which provides a BAC for those drivers without measured values, yielding a BAC for every driver in a fatal crash. This allows the division of drivers in fatal crashes into those with a positive BAC, for whom drinking could have played a role in the crash, versus those with a zero BAC, for whom, presumably, drinking was not a factor. This distinction allows separate trend analyses of alcohol and non-alcohol related involvement, which can provide a first step in understanding the change in trend after 1994.

Methods

An 18-year sample of all drivers in fatal crashes in the U.S. was extracted from the FARS file. The resulting file of 543,655 drivers was divided into two groups based on the measured (46.7% of the sample) or the imputed (53.3% of the sample) BAC of the driver at the time of the fatal crash. One group consisted of crash-involved drivers with zero BACs, while the second group included crash-involved drivers with BACs greater than zero. Of these drivers, 43.7% were fatally injured and 56.8% survived the crash in which they were involved. Separate 18-year trends covering males and females in two age groups, 16 to 20 and 21 to 34, were computed. The basic descriptive data are shown in Table 1. In addition, unemployment statistics for the nation as a whole were obtained from the Bureau of Labor Statistics from 1982 to 1998 and used to generate the total employment level (1- unemployment) for each of those years.

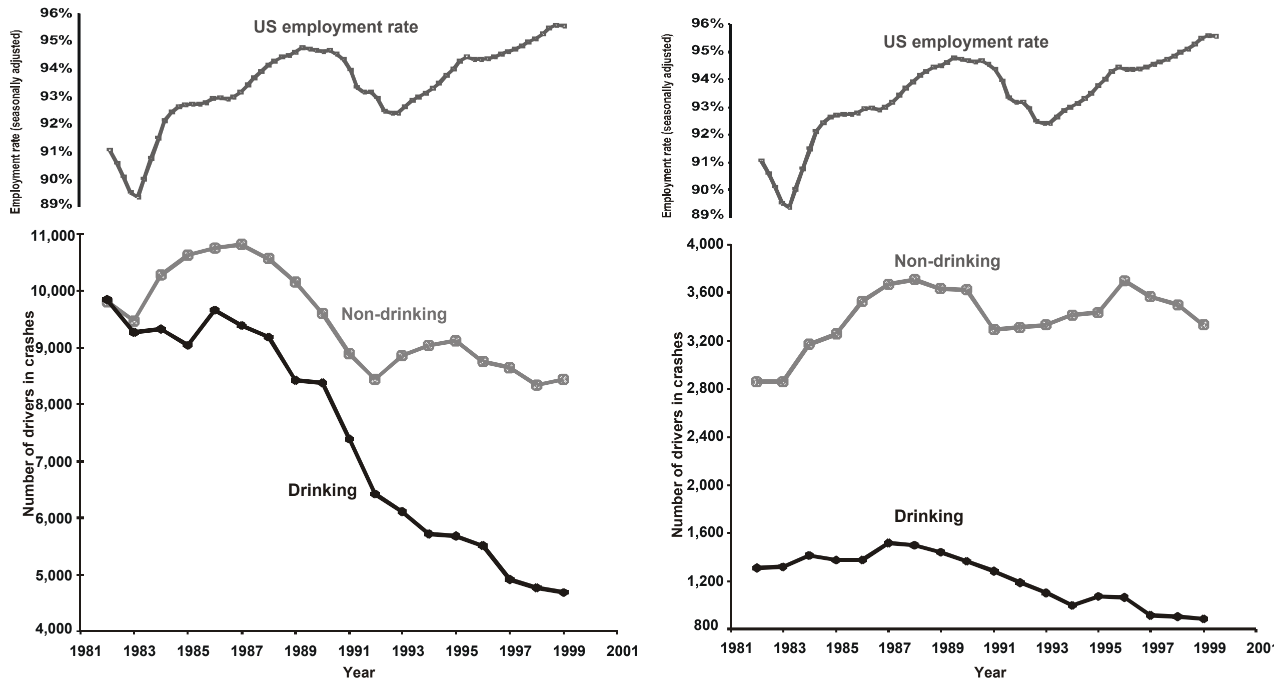
Table 1: Drinking and non-drinking drivers in fatal crashes

		Drinking			Non-drinking		
		16-20	21-34	Total <35	16-20	21-34	Total <35
Number of drivers	Male	40,461	133,709	174,170	76,863	170,656	247,519
	Female	7,017	22,010	29,028	31,659	61,250	92,908
	Total	**47,480**	**155,730**	**203,210**	**108,530**	**231,915**	**340,445**
Percent alcohol-involved	Male	34.5%	43.9%	41.3%			
	Female	18.1%	26.4%	23.8%			
	Total	**30.4%**	**40.2%**	**37.4%**			

Results

Figure 2 presents the trend in crash involvement from 1982 to 1999 of drinking and nondrinking male and female drivers between 21 and 34, the age group with the highest involvement in alcohol-related crashes and a special target group for federal drinking-driving programs. The upper portion of each graph shows the employment trend over the same period. As can be seen, there is a clear relationship between the employment level and crash involvement of zero-BAC drivers. The employment level dropped in 1983, and there was a corresponding dip in nondrinking driver crash involvement, followed by a rise as the employment level increased.. The crash involvement of the zero-BAC drivers paralleled the employment trend as it dipped in 1992 and '93 and then rose again. In contrast, the downward trend in drinking driver involvement in fatal crashes shows no relationship to the employment level, suggesting that other factors than the general economic prosperity account for the observed reduction. Further, while, as shown in Figure 1, the reduction in total alcohol-related fatalities off after 1994, this effect is not shown in the high risk group of 21 to 34 male drivers.

Figure 2: U.S. employment rate and the number of drinking and nondrinking drivers 21 to 34 in fatal crashes

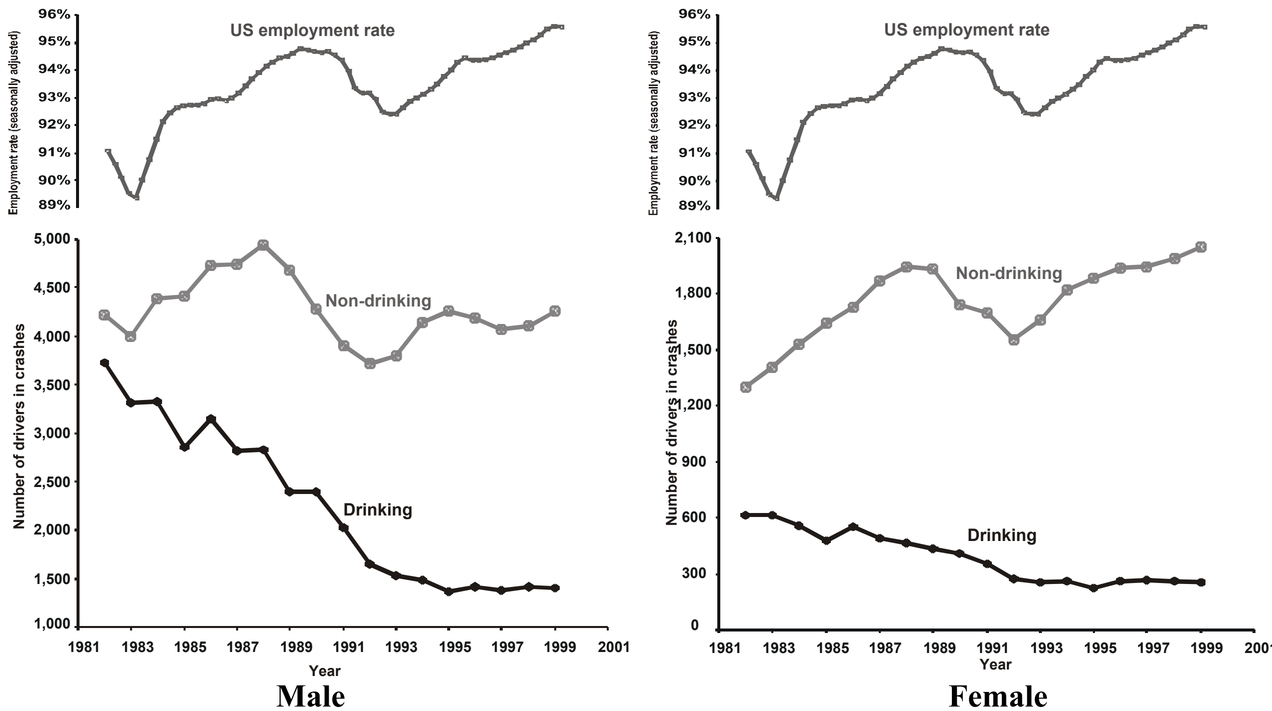


Male **Female**

As can be seen in Figure 2, the trend in nondrinking female involvements is similar to that of male drivers. The female trend follows the employment down turn from 1988 to 1993 and then rises again to 1996. However, female, total nondrinking involvement increased over the 1982 to 1999 period, whereas male involvement increased. During the same period, there was, as with males, a decrease in drinking female involvement that showed no relation to the employment level. The drinking female involvement also showed a continuation of the general downward trend through to 1999.

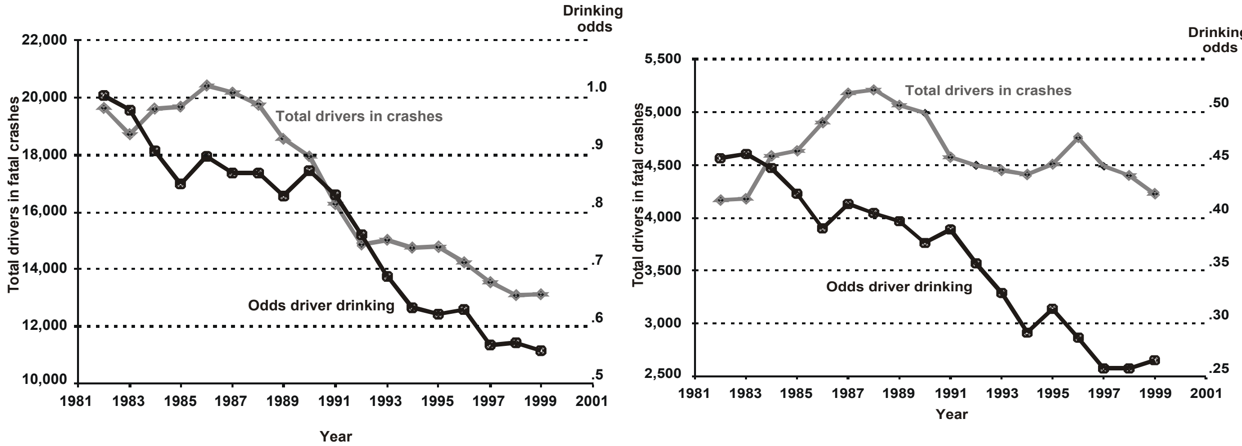
Figure 3 presents the same trend data for the 16 to 20 underage group of drivers. Once again, the involvement of both male and female drinking drivers appears to be influenced by the general employment level. However, the trend for the young crash-involved drivers with positive BACs differs from the older group. They fall steadily from 1982 to 1993-94, leveling off beyond that point. In addition, there is no net change in the numbers of nondrinking male drivers over the 18-year period, while the under-21, nondrinking female drivers increased by over 50%.

Figure 3: U.S. employment rate and the number of drinking and nondrinking male and female drivers 16 to 20 in fatal crashes



The effect of these trends on the total number of crash-involved drivers is shown in Figures 4 and 5. As shown in Figure 4, the total number of male drivers in the 21 to 34 age group involved in fatal crashes in 1982 was approximately 20,000. That number dropped to 13,000 by 1999. Also shown in Figure 4 is the ratio of drinking (BAC>.00) to nondrinking (BAC = .00) drivers. This provides the odds that a driver involved in a fatal crash will have been drinking. In 1982, the odds that a male driver 21 to 34, in a fatal crash would have a positive BAC were approximately 1.00, while in 1999, the odds had fallen to .55. For females in the same age group, there was no overall reduction in total driver involvement but there was a reduction in the odds that a female crash-involved driver would be drinking from .45 to .25.

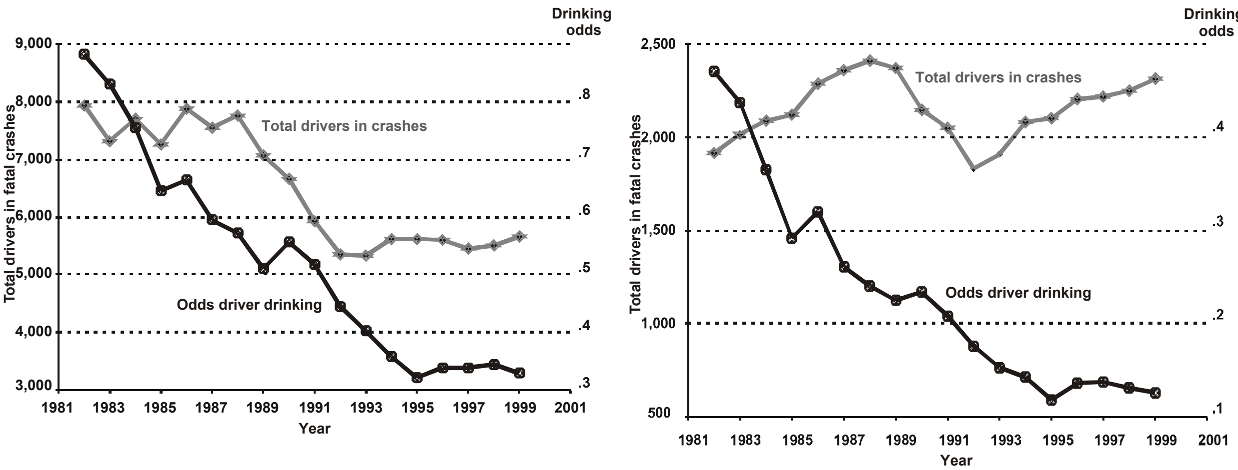
Figure 4: Total male and female drivers 21 to 34 in fatal crashes and the odds that such a driver will have been drinking



Male **Female**

The total number of young male driver involvement in fatal crashes was reduced by over a third from 8000 to just above 5000 between 1982 and 1999 (Figure 5). However, all of that reduction occurred between 1982 and 1992. While the drop in total crash involvement leveled off after 1992, the odds that a driver would be drinking continued to decline through 1995, after which the odds remained constant. Over the 1982 to 1995 period, the odds that a male driver would be drinking dropped by two thirds from .9 to .3. Meanwhile, total female fatal crash involvement increased, but the odds that a female driver would have been drinking decreased similarly to male drivers, from .48 to .11 (Figure 5). It is of particular interest that the total number of female driver involvement began to increase in 1992—the same time that the number of male involvements leveled off—but, as with the male involvement, the odds that the driver would be drinking continued to go down until 1995.

Figure 5: Total male and total female drivers 16 to 20 in fatal crashes and the odds that such a driver will have been drinking



Male **Female**

Discussion

Analysis of the trends for drinking and nondrinking drivers in fatal crashes separately reveals the extent to which the latter are influenced by the economy, while employment levels appear to have relatively little influence on the former. The economic boom that began in 1992 was associated with significant increases in the numbers of nondrinking female drivers in fatal crashes, apparently related to substantial increases in the miles driven by women. The number of male nondrinking drivers also increased during the period after 1992 to a somewhat lesser extent. However, for both genders the number of nondrinking driver involvement continued to decrease: through 1995 for underage drivers and to 1999 for drivers in the 21 to 34 age group. This presents a somewhat less bleak picture than examination of the total overall alcohol-related fatalities. Most of the recent advances in alcohol safety laws have been aimed at drivers (e.g., per se laws, .08 laws, Administrative License Revocation laws, zero tolerance laws). The continued decline in the number of drinking drivers in the high risk 21 to 34 age group up to 1999 suggests that the growth in the number of U.S. states with such laws is continuing to have an impact.

On the other hand, the leveling out of the decline from 1995-on for the under-21 age group remains to be explained. It was at that time that the U.S. Congress passed a law providing for the withholding of highway construction funds from states that did not enact a zero tolerance law, which makes it an offense for youths under 21 to drive with any amount of alcohol in their bodies. Unfortunately, enforcement of that law has been lax (3), as has the enforcement of the age-21 minimum legal drinking age law (4). Whether or not the failure of the number of underage drinking-drivers in crashes to continue to decline after 1995 can be explained by failure to enforce underage-drinking laws, the trends illustrated suggest continued attention to underage drinking and drinking and driving is warranted.

References

1. FARS. Fatal accident reporting system, 1999. Washington, DC: National Center for Statistics and Analysis, Highway Traffic Safety Administration; 2000.

2. Klein T. A method for estimating posterior BAC distributions for persons involved in fatal traffic accidents. Washington, DC: National Highway Traffic Safety Administration; 1986. DOT HS 807 094.

3. Ferguson SA, Fields M, Voas RB. Enforcement of zero tolerance laws in the US – Prevention Section. In: Laurell H, Schlyter F, eds. *Alcohol, Drugs and Traffic Safety – T 2000: Proceedings of the 15th International Conference on Alcohol, Drugs and Traffic Safety, May 22-26, 2000*. Stockholm, Sweden: ICADTS; 2000:713–718.

4. Toomey TL, Rosenfeld C, Wagenaar AC. The minimum legal drinking age: History, effectiveness, and ongoing debate. *Alcohol Health & Research World.* 1996; 20:213–218.

BAC and Fatal Crash Risk

David F. Preusser

PRG, Inc.
7100 Main Street
Trumbull, Connecticut

Keywords
Alcohol, risk, crash

Abstract
Induced exposure, a technique whereby not-at-fault driver crash involvements are used as the denominator in a risk estimate calculation, was used to estimate fatal crash risk by driver BAC. One important advantage of induced exposure is that large existing data sets provide substantial sample size for risk estimation. Risk ratios were calculated for BACs ranging from .01% to .20%. The results indicated that whereas case/control methods suggest an exponential or curvilinear relationship between crash risk and BAC, both induced exposure and laboratory findings suggest a linear relationship.

Introduction
Estimation of driver crash risk by specific BAC level has been difficult using existing laboratory and case/control methods. Nevertheless, BAC limits of precisely .02%, .04%, .06% and .08% have been established for various offenses affecting various classes of drivers. The objective of the present study was to estimate fatal crash risk for precise BAC levels using an alternative procedure, induced exposure, then compare the risk estimates obtained to both laboratory and case/control findings.

Moskowitz (2001) summarized laboratory and case/control research as follows: 1) Laboratory studies have found impairment at BACs as low as .01%; 2) Young people are more impaired at low BAC levels than older persons; 3) Excluding the young and the old, and using each subject as his/her own control, laboratory studies indicate that there is no differential alcohol effect as a function of age; 4) Laboratory studies suggest a linear increase in impairment with increasing BAC whereas case/control studies suggest an exponential increase. Each of these findings can be compared to results found using induced exposure risk estimation.

Induced Exposure
Induced exposure (see Preusser et al., 1998), is based on the concept that any driver on the road may be the victim in a multiple vehicle crash of some other driver's mistake. These "not at fault" multiple vehicle crash involvements can be used as a surrogate measure of exposure to highway risk. Drivers involved in a single vehicle crash and drivers who made a critical error leading to a multiple vehicle crash are considered to be "at fault."

In effect, at fault crash involvement becomes the numerator (i.e., measure of risky driving) and not at fault involvement in multiple vehicle crashes becomes the denominator (i.e., measure of exposure). Crash risk can then be calculated in relation to some reference group such as drivers ages 35-49 at .00% BAC (Table 1) or all drivers at .00% BAC (Table 2; after Clayton, 1977).

$$\text{Risk} = \frac{T_f B_{nf}}{T_{nf} B_f}$$

T = number of crash involvements for the target age driver at a specified BAC level (e.g., 16-20 year old drivers at .01% BAC)
B = number of crash involvements for drivers in the base driver group (e.g., ages 35-49 at .00% BAC)
f = at fault involvements
nf= not at fault involvements

One strength of the induced exposure technique is that it requires no assumptions for time of day, road type, vehicle type, type of area or other variables that might be related to high risk or low risk driving situations. Types or groups of drivers who drive more in high risk situations should have proportionately greater opportunity for "induced" exposure than groups of drivers who drive more in low risk situations.

Fatally injured drivers of passenger vehicles were identified in FARS for the years 1987-99. Each driver was categorized as being "at fault" or "not at fault" in the crash. At fault was defined as: being involved in a single vehicle crash; or being assigned one or more driver level factor codes 20 to 59 (i.e., behavioral errors). Passenger vehicles were defined as cars, vans, light trucks and utility vehicles. Drivers of motorcycles, motor homes, farm equipment, buses, medium trucks and heavy trucks were excluded as were drivers for which BAC or age was unknown. Also excluded were crashes involving a pedestrian or bicyclist. The full data set, after these exclusions, contained 192,282 fatally injured drivers of which 33,146 were "not-at-fault."

Results

Table 1 shows risk calculations by driver age and BAC. Calculations are normalized to a risk of 1.00 for drivers ages 35-49 at .00% BAC. As shown in the first column, per unit of exposure, young drivers ages 16-20 at .00% BAC are three times more likely to become fatally injured in a motor vehicle crash than drivers ages 35-49 at .00% BAC. Drivers ages 65 and older are two times more likely. Remaining columns show risk for each age group with increasing BAC.

Table 2, first row, shows risk calculations normalized to 1.00 for drivers of all ages at .00% BAC. The comparable risk calculations from Grand Rapids (Borkenstein, 1964 as summarized by Hyman, 1968) are shown in the second row of Table 2.

Table 1: Crash Risk by Age and BAC (FARS 1987-99, N = 192,282)

	Blood Alcohol Concentration								
AGE	00	01	02-03	04-05	06-07	08-09	10-14	15-19	20+
16-20	3.31	4.37	4.12	5.44	8.17	10.10	15.77	25.30	28.19
21-24	1.79	2.18	2.59	4.42	6.11	8.13	10.73	16.43	26.00
25-34	1.25	1.38	1.89	2.32	2.94	4.37	7.27	11.61	16.08
35-49	1.00	1.09	1.49	1.78	2.62	3.56	5.64	10.44	16.99
50-64	1.02	0.93	1.17	1.24	2.03	2.23	4.71	8.48	13.24
65 +	2.04	1.97	2.49	2.50	2.50	3.55	4.83	7.48	9.48

Table 2: Crash Risk by BAC (FARS 1987-99 - Grand Rapids)

Erreur ! Signet non défini.	Blood Alcohol Concentration								
	00	01	02-03	04-05	06-07	08-09	10-14	15-19	20+
FARS	1.00	1.07	1.36	1.72	2.44	3.28	5.21	8.27	11.37
G. R.	1.00	0.91	0.89	1.13	1.46	1.89	5.70	17.11	23.62

1) Impairment can be found at BACs as low as .01%.
   Table 1 indicates somewhat increased risk at .01% BAC for all age groups through age 49; decreased risk for age groups above age 49. However, none of the increases or decreases shown in Table 1 for any of the age groups, .00% BAC versus .01% BAC, were statistically significant. At .02% BAC, a statistically significant increase in risk was found for age groups 21-24, 25-34 and 35-49. For 16-20 year-olds the first BAC level to show a statistically significant increase in risk was .03%. For 50-64 year-olds the first BAC level was .06% and for drivers ages 65 and older the first level was .08%.

   Table 2 shows that for drivers of all ages fatal injury crash risk was 1.07 at .01% BAC versus 1.00 at .00% BAC. This difference was not statistically significant ($\chi 5 = 1.66$, ns with 1 df). However, at .02% BAC fatal crash risk increased to 1.24. This difference, 1.24 versus 1.00, was statistically significant ($\chi 5 = 14.49$, $p<.001$ with 1 df). Therefore, induced exposure methods indicate a statistically significant increase in crash risk beginning at .02%.

2) Young people are more impaired at low BAC levels than older persons.
   As shown in Table 1, young drivers are clearly at greater risk at lower BACs than older drivers. However, they are also at greater risk at .00% BAC, moderate BAC and high BAC.

3) Excluding the young and the old, and using each subject as his/her own control, there is no differential alcohol effect as a function of age.
This is one of the more interesting findings from the laboratory studies. While each age group may start at a different level, the ratio or multiplicative increase in impairment arising from increasing BAC is similar.

The results shown in Table 1 are consistent with this finding. For all age groups 20 through 64, risk increases by a factor of about five or six at .10% BAC; by a factor of about thirteen for BACs of .20% and above.

This constant relationship by age does not hold for younger or older drivers. For drivers ages 16 through 20, risk starts at 3.31 for .00% BAC. Risk shows multiplicative increases similar to other age groups through .10% BAC; then risk increases more slowly. For drivers ages 65 and older, the increase in risk as a function of BAC is much smaller as compared to other age groups over the entire BAC range.

4) Laboratory studies suggest a linear increase in impairment with increasing BAC whereas epidemiological studies suggest an exponential increase.
Currently, the primary available epidemiological case/control data set is Grand Rapids (Borkenstein et al., 1964). Table 2 compares Grand Rapids with the current study. The results indicate that the Grand Rapids risk estimates are well below the induced exposure estimates for all BAC levels up to .09%. Grand Rapids is approximately equal to induced exposure at .10% BAC then rises rapidly. For BACs of .20% and above, crash risk estimated from Grand Rapids is approximately double the crash risk estimated by induced exposure. The Grand Rapids results clearly suggest a curvilinear relationship between BAC and risk whereas the induced exposure results, consistent with laboratory findings, clearly suggest a linear relationship.

Why do case/control results differ from both induced exposure and the laboratory?

Case/control studies are based on comparisons between crash involved drivers and similarly exposed, yet non-crash involved, controls sampled same time of day, same day of week at the crash location. An inherent bias of this methodology is that any real differences between the crash and non-crash groups will be diminished to the extent that drinking itself is correlated with time of day, day of week and location irrespective of any increased risk due to alcohol. For instance, if the incidence of drinking correlates 100% with time of day, day of week and location, then it is a logical impossibility to find a crash versus control difference based on the presence or absence of alcohol. Each control subject will be found to have been drinking every time the crash involved driver was drinking; each control subject will be found not to have been drinking every time the crash involved driver was found not to have been drinking. This is true whether the increased risk due to alcohol is 0 percent, 10 percent or 1,000 percent.

Consider, for instance, the following extreme example. There is a dead-end road leading only to a social club and a religious facility. Every driver going to or from the club has been drinking. Every driver going to or from the religious facility has not been drinking. By mutual agreement, the club and the religious facility are never open at the same time of day, day of week. Thus, every time there is a crash involving a driver from the club, that driver will have been drinking as will every control driver sampled to correspond with that driver. Similarly, every time there is a crash involving a driver from the religious facility, that driver will not have been drinking and every control driver sampled to correspond with that driver will not have been drinking. No increase in risk associated with alcohol will be found even though there may be five, twenty-five or fifty crashes involving a driver from the club for every one crash involving a driver from the religious facility. That is, overall risk for drivers who had been drinking will be calculated at 1.00; overall risk for drivers who had not been drinking will be calculated at 1.00.

While the overall risk for the presence or absence of alcohol may be 1.00 in the above example, it is not necessarily true that calculated risk will be 1.00 for every BAC level. The high BAC drivers from the club could be the ones that are crashing while drivers at lower BAC may be found more often in the control group. Still, overall risk must sum to 1.00. Algebraically, then, we would expect risk estimates that are less than 1.00 for low BACs; higher than 1.00 for high BACs; summing to an overall risk of 1.00. Any such downward bias for low BACs, and upward bias for high BACs, in case/control studies would have the effect of creating the appearance of an exponential risk by BAC relationship.

If the true relationship between BAC and risk is linear, then it follows that countermeasures need to be concerned with the full range of BAC levels. It is just as important to lower a BAC level of a drinking driver from .05% to .04% as it is to lower a level from .15% to .14%. Moreover, viewed on a population basis, it may be more important to lower the .05% BACs since there are far more drivers on the road with low as opposed to high BACs.

Conclusion

The present results, consistent with laboratory findings, indicate that BACs as low as .02% increase fatal crash risk. Relative increases in crash risk by BAC appear to be consistent across all age groups, young and old excluded. The shape of the BAC by risk function is likely linear, not exponential as suggested by earlier case/control studies. If linear, it becomes even more important to address low BACs in any comprehensive effort to reduce alcohol related crashes.

References

Borkenstein, R.F., Crowther, R.F., Shumate, R.P., Zeil, W.B., Zylman, R. (Dale, A. ed.) The Role of the Drinking Driver in Traffic Accidents. Indiana University, Department of Police Administration, 1964.

Clayton, A.B., Booth, A.C., McCarthy, P.E. A Controlled Study of Alcohol of the Role of Alcohol in Fatal Adult Pedestrian Accidents. Crowthorne, Berkshire, UK: Transport and Road Research Laboratory, 1977. Supplementary Report #332.

Hyman, M.M. Accident vulnerability and blood alcohol concentrations by demographic characteristics. Quarterly Journal of Studies on Alcohol, 1968, Supplement No.4, 33-57.

Moskowitz, H. Laboratory Studies of the Effects of Low BAC on Performance. Paper presented at the Transportation Research Board Workshop, Woods Hole, MA, August, 2001.

Preusser, D.F., Ferguson, S.A. and Williams, A.F. The effect of teenage passengers on the fatal crash risk of teenage drivers. Accident Analysis and Prevention, 1998, 30(2), 217-222.

A Review of Experimental Studies of Low BAC Effects on Skills Performance

H. Moskowitz and D. Fiorentino

Southern California Research Institute, Los Angeles, CA, USA

Keywords
Alcohol, literature review, low BAC's, experimental studies, skills performance.

Abstract
This article reviews a recent period of 15 years of experimental studies of driving related performance skills under low BAC levels. It concludes that different behavioral areas exhibit sharp differences in both the threshold BAC level at which impairment appears and the magnitude of impairment. Several major areas that are important for traffic safety demonstrate significant impairment at the lowest BAC levels examined.

Introduction
One of the major debates in public policy discussions of drinking-driving countermeasures has been the legal blood alcohol concentration (BAC) permitted for driving. These debates have been influenced by epidemiological studies on the relationships between BAC and collision probabilities, and by experimental studies on the relationship between BAC and skills performance impairment.

In a 1988 report, Moskowitz and Robinson (1) summarized the experimental literature from 1950 through 1985 dealing with alcohol effects on driving related performance. 177 studies which met acceptable scientific standards such as; placebo treatments, statistical significance and the ability to determine BAC levels at behavioral testing periods were included in that report. By .04 g/dl BAC, 21% of the studies reported significant impairment. By .05 g/dl, 34% of the studies reported impairment. 66% of the studies reported impairment by .08 g/dl and nearly all by .10 g/dl.

The BAC's at which impairment first appeared and the percent of studies reporting impairment at various BAC's differed by behavioral response area. Studies requiring divided attention, various visual functions and tracking demonstrated impairment beginning at .01 g/dl. Conversely, simple reaction time studies appeared quite insensitive to alcohol treatment. The review criticized many studies for examining performance at only one BAC. Thus, a report of impairment at a single BAC sheds no light on whether a lower BAC might also be impaired. The report also suggested that the description of behavioral areas in many of the studies were inadequate in their description of the experimental task or response measure. This meant placement of the study within a behavioral domain area was often difficult.

Subsequently, Kruger, et al. (2) in1993, and Holloway in 1994 (3) and 1995 (4) reviewed large samples of experimental studies under alcohol. They also organized the experimental studies into behavioral domain areas, but used categories other than Moskowitz and Robinson. These reviews also concluded that many components of the driving task are impaired by BAC's below .05 g/dl.

This current paper will summarize a review of the literature published from 1981 to 1998 on driving related behavior under low BAC's.

Method

A computer search of the literature for the 1981 to 1998 time period on the effects of alcohol on driving related skills performance produced abstracts for 1,733 titles. Studies were excluded if they were not reported in English or dealt with more subjective areas of behavior such as motivation, aggression, etc. 358 articles were initially selected for retrieval, but library resources were only able to obtain 285. These 285 retrieved published studies were then evaluated to determine if they met further inclusion criteria. The inclusion criteria required that; behavioral response measures could be seen as clearly driving related, that the experimental procedure specified the BAC at the time of behavioral testing, or that the BAC at behavioral testing time could be calculated from the times of the alcohol administration and the times of the behavioral testing, and that the alcohol effects were not confounded with other drug treatments. At total of 112 studies remain, which met all the inclusion criteria for enrollment in the literature survey. Many of the studies examined more than one behavioral domain and most studies examined these areas at more than one BAC level.

Results

Only two of the 112 studies failed to find evidence of impairment at some alcohol level tested. These two only utilized one BAC level. A third study only examined the after-effects of alcohol ingestion without any examination of effects under an active alcohol treatment level.

The remaining 109 studies all reported impairment by alcohol at one or more BAC levels. The majority of studies reported impairment by .05 g/dl. 94% of the studies reported impairment by .08 g/dl.

The studies were organized by the behavioral areas they were presumed to examine. The criterion for inclusion in a behavioral area was determined by the statement of the author or authors of the experimental study. The authors of the literature review often had questions whether a particular study did or did not include the behavioral domain stipulated by the experimenters. However, such a determination was left to those who performed the experiment.

The research reports were placed into 13 behavioral categories or areas. These areas were; after-effects,(that is, impairment after zero BAC has been reached), cognitive, critical flicker fusion, driving in either a simulator or on the road, perception, psychomotor tasks, choice reaction time, simple reaction time, tracking, vigilance, visual functions, and drowsiness.

Similar to the results found in prior literature reviews, the lowest BAC at which impairment was found and the BAC at which 50% or more of the behavior exhibited impairment varied considerably between the behavioral areas. Critical flicker fusion and simple reaction time studies were the behavioral areas most insensitive to the effects of alcohol. On the other hand, tests in the behavioral areas of divided attention and of driving exhibited impairment by .01 g/dl.

The majority of behavioral tests on drowsiness exhibited impairment by .02 g/dl. The majority of tests of vigilance exhibited impairment by .04 g/dl. Moreover, these areas above exhibited agreement in that nearly all studies produced evidence showing impairment at nearly all of the various BAC levels that were examined. Similarly, there was little variability in the results from the studies of simple reaction time and critical flicker fusion. However, in these studies the strong agreement was in the failure to find evidence of impairment.

There was considerable variability in the reports of impairment at various BAC in studies examining the behavioral area of tracking, perception, visual function, cognitive task, psychomotor skill and choice reaction time . Studies within each of these behavioral areas differed considerably in the BAC level at which impairment appeared. Closer examination of the behavioral tasks within each of these behavioral domains suggested that the criteria utilized by the authors for placing the behavior within that domain were so inclusive that they covered behaviors which truly were quite variable in what they required of the subjects. For example, the following are some experimental tasks included in studies the experimenters identify as cognitive: digit-symbol substitution, serial addition and subtraction, memory tasks, reading comprehension, card sorting, color test, visual backward masking, velocity estimation, grammatical reasoning, mathematical processing, pattern discrimination, spatial orientation, to mention but roughly half the tasks under cognition. It can be clearly recognized that the tasks do not present a homogeneous behavioral requirement for subjects. Thus, it is not surprising that there is considerable variability within the behavioral domain regarding the BAC threshold of appearance of impairment. Many of these behavioral tasks demonstrated impairment at extremely low BAC's whereas others were far more resistant. Unfortunately it is difficult for a reviewer to break down the tasks within these areas merely by reading the experimenters publication. In fact, part of the difficulty rests on the limitations in the current state of cognitive science in being able to define all the cognitive processes involved in a given behavioral task. It should be noted that most of the six behavioral areas which showed the least degree of variability in results were those with more tightly defined behavioral measures. The more clear-cut and unambiguous the definition of the behavioral demand area appears the less variability and great unanimity of results under alcohol obtained.

From the viewpoint of scientific inquiry into the character of the diverse effects of alcohol on different behavioral areas, there still remains considerable work to be done. There is also clearly a necessity to study alcohol's effect on less clearly defined and investigated areas such as risk taking, aggression and motivation. However, the results of this literature review confirms that of previous literature review, that there are behavioral areas crucial to driving, such as vigilance, drowsiness and divided attention, to name but a few, that are impaired at any departure from zero BAC. Clearly, even the lowest possible doses of alcohol carry a penalty when consumed in conjunction with the complex task of automobile driving.

References

1. Moskowitz, H. & Robinson, C.D. (1988). Effects of low doses of alcohol on driving-related skills: A review of the evidence. (Report No. DOT HS 807 280) Washington, DC: national Highway Traffic Safety Adminstration, SRA Technologies, Inc.

2. Kruger, H.P. (1993). Effects of low alcohol dosages: A review of the literature. In: Utselmann, H. –D., Berhaus, G., & Kroj, G. (Eds.), Alcohol, Drugs and Traffic Safety – T'92: Proceedings of the 12th International Conference on Alcohol, Drugs and Traffic Safety, Cologne, 28 September – 2 October, 1992 (pp 763-778). Cologne: Verlag TUV Rheinland.

3. Holloway, F.A. (1994). Low-Dose Alcohol Effects of Human Behavior and Performance: A Review of Post-1984 Research. Washington, DC: Department of Transportation, Federal Aviation Administration, office of Aviation Medicine Technical Report DT/FAA/AM-94/24 (pp 47)

4. Holloway, F.A. (1995). Low-dose alcohol effects on human behavior and performance. Alcohol, Drugs and Driving, 11(1), 39-56.

The Effects of Low BACs on Driving Performance

M. Burns and D. Fiorentino

Southern California Research Institute
Los Angeles, California, USA

Abstract
The scientific literature provides evidence that driving skills are impaired at low blood alcohol concentrations (BACs), but it does not identify the *behaviors* and *driving patterns* associated with those alcohol levels. This paper addresses the question of whether observable behavioral signs of alcohol influence and /or alcohol-specific driving patterns occur reliably at low BACs.

Introduction
At 0.10% BAC, drinkers exhibit observable signs of intoxication on at least some drinking occasions. At or above 0.15% BAC, they are obviously intoxicated unless they are chronic, heavy drinkers. At lower alcohol levels alcohol effects are more difficult to detect, and there are consequences of that difficulty for both alcohol consumers and law enforcement.

If a drinker does not *feel* intoxicated and if no evidence of alcohol influence is directly available to him, he may believe that he can drive safely. For traffic officers, enforcement of driving-under–influence (DUI) laws is an extremely difficult task when neither a driver's behavior nor his driving departs from the norm. The difficulty is believed to account for the fact that the most frequent roadside error by officers in a Colorado field study (1) was the failure to arrest DUI offenders, presumably because they did not correctly assess alcohol impairment. To address this issue, the *nature* of performance deficits and the *characteristics* of impaired drivers were examined with a set of driving simulator data.

Method
Data were obtained with the Southern California Research Institute (SCRI) simulator, a computer-based instrument that presents wide-angle driving scenes on three large screens. It has side- and rear-view mirrors, and provides realistic visual and sound feedback. Subjects steer, accelerate and brake as they respond to the varying demands of rural, suburban and urban driving scenes. As a secondary task, they also perform a visual search for peripheral signals. For this study, key measures (Table 1) were selected from a larger data set generated in a study with 168 subjects (2). Six selected measures and three BACs (0.00%, 0.04%, 0.08%) from alcohol sessions were analyzed. These six measures were significantly impaired at 0.08% BAC in the larger study.

From the secondary task, the Reaction Time (RT) measure was selected for analysis, because it is expected to reflect the slowing of information processing by alcohol. The measure Correct

Responses, also from the secondary task, was selected to capture attention deficits. The selected variables from the simulator were measures of car control. It was not expected that psychomotor skills would be so degraded at low BACs as to affect these measures, but it was possible that they would be affected by euphoria, relaxed inhibitions, and attention deficits.

Table 1: Driving Simulator Measures

Secondary Task
Reaction time (sec)
Correct detections (number)
Simulator Operation
Speed Deviation (mph)
Lane Deviation (ft)
Collisions (number)
Posted speed exceeded (number)

Results

The performance measures (mean, std. dev.) appear in Table 2. Note the absolute changes. At 0.08%, the changes in RT, lane deviation, collisions and speeding incidents were of sufficient magnitude to have potentially serious consequences. At 0.04%, a one-half foot increase in mean lane deviation is not large, but it is noteworthy nonetheless. Alcohol-impaired drivers typically allocate their reduced capacity to the continuous demands of steering, and initial losses occur in other components of the driving task. This increase in lane deviation suggests a deficit in attention to steering even at a low BAC.

Traffic officers frequently detect DUI drivers at ≥ 0.08% BACs as a result of their excessive speed. Subjects at 0.04% also exceeded the posted speed limit roughly twice as often as at zero BAC. This significant increase suggests that they paid less attention to posted speed limits and failed to monitor acceleration either because of reduced central capacity or because of lessened concern about the violation. The number of collisions increased from slightly more than four at 0.00% to almost six at 0.04%, a significant change and a negative consequence of a low BAC. In contrast, the 0.1second increase in response time to peripheral signals, although statistically significant, probably is trivial in terms of consequences for driving.

Subjects were significantly impaired on all measures at 0.08% as compared to 0.04%. At 0.04% BAC compared to 0.00%, secondary task RT and the simulator measures of lane deviation, collisions, and speed limit violations were significantly impaired (Table 3).

This analysis suggests that the magnitude of performance deficits will enable trained observers to recognize impairment at 0.08% BAC. That conclusion is supported by traffic officers' arrests at that level. What is unknown, of course, is the frequency with which officers encounter but fail to recognize drivers at 0.08%.

At 0.04% BAC, there are few obvious signs, and a lay observer probably would not recognize impairment at that level. Traffic officers are skilled observers and may be able to detect alcohol influence at 0.04% if they are trained to accept lesser driving errors as evidence. Weaving, for example, as it frequently appears in traffic reports, reflects large vehicle excursions rather than the small deviations noted here.

Table 2: Performance Measures with Placebo and Alcohol Treatments

	Mean	*Std. Dev*	*Mean*	*Std. Dev.*	*Mean*	*Std.Dev.*
	0.00%		0.04%		0.08	
Peripheral Signals						
RT (sec)	2.87	.62	2.96	.62	3.12	.63
Correct (number)	58.00	12.41	57.20	12.77	53.80	14.01
Simulator Operation						
Speed Deviation (mph)	3.44	1.88	3.38	1.61	3.78	1.58
Lane Deviation (ft)	1.31	.37	1.79	.66	2.05	.87
Collisions (.number)	4.2	6.29	5.8	9.46	9.7	12.26
Speed limit exceeded (#)	4.4	5.11	9.2	8.99	12.1	10.52

Table 3: Simulator Measures Paired t Tests

	0.00 – 0.04%_			0.04% - 0.08%.		
	t	df	p	t	df	p
Peripheral Signals						
RT (sec)	3.02	164	.003	5.07	156	.000
Correct (number)	-1.40	164	.164	-4.88	156	.000
Simulator Operation						
Speed Deviation (mph)	-.34	166	.732	3.25	158	.001
Lane Deviation (ft)	11.10	166	.000	5.15	158	.000
Collisions (.number)	2.95	166	.004	6.04	158	.000
Speed limit exceeded (#)	8.43	166	.000	5.53	158	.000

[1] $N_{Total\ Sample} = 168$ $df_{paired\ t}$ = N-1 for complete pairs.

Driver Characteristics

Truisms about alcohol include that women are more affected by alcohol than men, young drinkers become intoxicated more readily than older drinkers, and naïve drinkers are more impaired than chronic drinkers. If women, youth, and naïve drinkers display signs of alcohol at lower BACs than others, that knowledge might aid police officers in the recognition of alcohol influence.

To examine the question of *who* is most susceptible to alcohol, the percent change between three alcohol conditions was examined for men compared to women, for four age groups, and for light, moderate, and heavy drinkers (Tables 4, 5, and 6). The largest percent changes appear in **bold** in the tables.

The data cast doubt on the belief that women are more impaired than men at low BACs (Table 4). Men showed the greatest increase in excessive speed and in number of collisions at both 0.04%

and 0.08%. They also showed a greater increase in impairment on the secondary task. Women displayed greater increases in speed and lane deviations.

The youngest subjects, ages 19 - 20 yrs showed the largest changes for 10 of 18 comparisons. The relative change in performance was smallest on all measures for the oldest group of drivers, ages 51 - 69 yrs (Table 5). Their performance at zero BAC is affected by the age variable itself, but they showed less relative change with alcohol than younger subjects.

Table 4: Relative Performance Change by BAC For Male and Female Subjects

	Score Change (Percent)					
	0.00% → 0.04%		0.00% → 0.08%		0.04% → 0.08%	
	Men	Women	Men	Women	Men	Women
Peripheral Signals						
RT (sec)	**5.31**	.99	**11.43**	6.07	**5.82**	5.03
Correct (#)	**-3.32**	.57	**-10.86**	-4.10	**-7.80**	-4.64
Simulator Operation						
Speed Deviation (mph)	-7.67	**4.53**	7.57	**10.78**	**16.51**	5.98
Lane Deviation (ft)	35.78	**37.37**	**56.85**	55.55	**15.52**	13.23
Collisions (#)	**50.94**	32.61	**168.83**	104.93	**78.10**	54.53
Speed limit exceeded (#)	**120.95**	95.81	**179.78**	164.33	26.52	34.99

The data in Table 6 provide little evidence either of protection against alcohol effects as a result of tolerance for heavy drinkers or of acute vulnerability to alcohol effects for light drinkers. Heavy drinkers showed the largest percent changes in seven comparisons. Moderate drinkers showed the largest change in six comparisons, and Light drinkers showed the largest change in five comparisons. Since age is a potentially confounding variable, note that the mean ages of light, moderate, and heavy drinkers did not differ significantly (33.6 yrs, 34.6 yrs, and 33.4 yrs, respectively).

A number of the between-drinking category differences are so small as to lack meaning. Of interest, however, is the lack of evidence in six measures that the *behavioral* tolerance, which develops as a result of chronic, heavy drinking, also extends to *driving performance*. Heavy drinkers' performance of the secondary task showed more deterioration, both at 0.04% and 0.08% BAC than other subjects. Although the performance of light drinkers clearly was influenced by alcohol at .04% and .08% compared to 0.00% BAC, the magnitude of the effect did not differ markedly from the other drinking groups.

Table 5: Relative Performance Change by BAC For Subjects in Four Age Groups[1]

	Percent Change					
	0.00% → 0.04%		0.00% → 0.08%		0.04% → 0.08%	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Peripheral Signals						
RT (sec)	**9.52**	6.15	**18.18**	11.75	**7.91**	5.18
Correct (#)	**-7.38**	-3.71	**-11.64**	-7.71	**-4.59**	-4.15
Simulator Operation						
Speed Deviation (mph)	-4.78	**3.45**	8.95	7.99	14.43	4.31
Lane Deviation (ft)	34.51	**43.04**	55.49	59.57	15.60	11.56
Collisions (#)	**183.33**	81.58	**386.11**	177.66	71.57	52.92
Over Speed limit (#)	**223.40**	169.38	**323.35**	212.13	30.90	30.72
	Group 3	Group 4	Group 3	Group 4	Group 3	Group 4
Peripheral Signals						
RT (sec)	.48	-1.88	5.70	1.74	5.19	3.70
Correct (#)	3.03	4.27	-5.65	-4.24	**-8.42**	-8.16
Simulator Operation						
Speed Deviation (mph	1.18	-3.73	**18.55**	4.13	**17.17**	8.16
Lane Deviation (ft)	29.85	39.33	56.64	53.75	**20.63**	10.35
Collisions (#)	-1.27	27.15	139.92	81.54	**143.00**	42.78
Over Speed limit (#)	83.33	53.47	155.16	85.41	**39.18**	20.81

[1] **Group 1** 19 – 20 years; **Group 2** 21 – 24 years; **Group 3** 25 – 50 years; **Group 4** 51 – 69 years

Table 6: Relative Performance Change by BAC For Light (L), Moderate (M), and Heavy (H) Drinkers

	Percent Change								
	0.00% → 0.04%			0.00% → 0.08%			0.04% → 0.08%		
	L	M.	H	L	M.	H	L	M	H
Peripheral Signals									
RT (sec)	3.31	.80	**5.07**	7.73	8.16	**10.17**	4.78	**7.31**	4.85
Correct (#)	-1.90	1.20	**-3.56**	-7.94	-6.76	**-7.95**	-6.16	**-7.86**	-4.55
Simulator Operation									
Speed Deviation (mph)	3.31	-11.75	**5.94**	**19.45**	-2.77	13.54	**15.64**	10.19	7.18
Lane Deviation (ft)	**43.82**	34.76	31.84	39.52	**64.74**	62.51	-2.99	22.25	**23.27**
Collisions (#)	**53.41**	50.00	22.66	116.53	**171.00**	117.94	41.14	**80.67**	77.68
Speed limit exceeded (#)	129.46	68.88	**136.40**	**197.26**	134.23	193.69	29.55	**38.69**	24.23

Discussion

Although impairment occurs at low BACs, the average driver likely will not be aware of changes in his/her driving abilities. This strongly suggests that the recommendation for the driving public should be to avoid driving after *any* alcohol consumption.

It is questionable whether current DUI enforcement methods could reliably enforce a limit lower then 0.08% BAC. A trained police officer may sometimes detect signs of driving impairment at lower BACs, but observations of relatively small car control errors require a more extended time period than typically is an option for an officer on traffic patrol. Furthermore, to confirm a low BAC once a driver has been stopped, officers would have to rely on a PBT. Behavioral signs will be minimal in many cases.

Importantly, these data indicate that youthful drinkers, who by reason of age are relatively inexperienced drinkers and drivers, may become dangerous drivers with even small amounts of alcohol. The policy for traffic officers should be to investigate for alcohol influence, even in the absence of behavioral signs, whenever young drivers are speeding or are involved in a collision.

References

1. Burns M, Anderson E. A Colorado validation study of the standardized field sobriety test (SFST) battery. Colorado Department of Transportation, Denver (CO) 1995.

2. Moskowitz H., Burns M., Fiorentino D., Smiley A., Zador P. Driver characteristics and impairment at various BACs. National Highway Traffic Safety Administration, Washington (DC) 2000, DOT HS 809 075

Low Blood Alcohol Content:
Overview of Performance, Safety, and Policy Implications

K. Stewart

Safety and Policy Analysis International, Lafayette, California USA

Keywords
Alcohol, performance, effects, prevention

Abstract
A workshop organized by the Transportation Research Board Committee on Alcohol, Drugs, and Transportation provided a forum for discussing and integrating current knowledge on various aspects of low blood alcohol content. The paper describes some of the issues that emerged at the workshop.

Introduction
In recent years, increasing attention has been paid to the effects of low levels of alcohol on performance and safety. Lower blood alcohol limits have been set for driving in many countries, for drivers under 21 in the United States, and for operators of commercial vehicles and all pilots. What is the scientific basis for these policy changes? Are further policy changes suggested by research? What public safety messages are supported? A workshop organized by the Transportation Research Board Committee on Alcohol, Drugs, and Transportation provided an opportunity to review and synthesize the available research on the performance and safety effects of low levels of blood alcohol content (BAC) and to draw conclusions based on the synthesis.

Methods
The workshop covered several major topics, including:

1 Experimental evidence of effects of low BACs on performance, including both laboratory testing of performance and testing on driving simulators
2 The various factors that enhance or mitigate the effects of low BACs
3 The epidemiology of low BACs in traffic, including the number and characteristics of drivers with low BAC in the traffic flow and the incidence of crashes involving drivers with low BACs.
4 The risk of harm associated with low BAC in various situations
5 The effects of policies lowering BAC limits
6 The policy implications of the research findings

Papers were written and presented by experts in each of the areas and responses to the papers were prepared and presented by discussants. Each of the topics was then discussed by the group as a whole and conclusions were formed based on the papers and discussions. .

Results

Several overarching conclusions came out of the presentations and discussions. These conclusions may be useful to policymakers and researchers in the transportation safety field.

Evidence of impairment

Measurable impairment of performance begins at the lowest blood alcohol levels - .02 percent and even .01 percent in some tasks. Not all performance measures are affected equally. While there is some interpersonal variation, it has been found that there are no consistent differential effects of age, gender, or drinking history on the effects of alcohol on performance.

Epidemiological studies, including case control studies of traffic crashes, are consistent with the experimental evidence on the effects of low levels of alcohol. The convergence of evidence from these two lines of research provides the scientific justification for low legal limits for alcohol in drivers and other transportation operators.

Performance versus behavior

While *performance* on a variety of cognitive and psychomotor tasks is measurably impaired at very low levels of BAC, overt, observable *behaviors* are not dependably changed by alcohol. Thus, an individual's driving performance may be impaired while behavior is not obviously affected by alcohol. This situation makes individual judgments about fitness to drive unreliable. Thus, a person who is drinking might not feel impaired or appear impaired to companions, but actually is impaired on important driving-related tasks. Similarly, enforcement based on observation of impaired behavior is difficult. In fact, law enforcement officers have been shown to be very unreliable in their ability to determine whether or not a driver is impaired even when they are given the opportunity to observe the driver closely.

In the United States, the legal structure requires that police have "probable cause" for stopping and testing a motorist. That is, there must be some observable behavior or other sign to indicate that alcohol might be present. This amounts to a behavior-based enforcement system and thus makes enforcement more difficult than in countries that permit chemical testing more broadly, for example in random breath testing. This problem could be reduced through the widespread use of passive breath sensors in sobriety checkpoints and in normal traffic patrols. These sensors can detect the presence of alcohol without violating legal restrictions, thus identifying drivers who should be examined further.

The effects of lowered legal limits

Research indicates that lowering the legal alcohol limit for drivers has resulted in safety improvements. The types and rigor of methods used to evaluate the effects of changes vary, as does the strength of the results. In most but not all cases, improvements have occurred in countries when the limit has been lowered to .05 and below and in the United States when the limit has been lowered to .08 in some states and to .02 or lower for drivers under 21. The size of the effects varies and the duration of the improvement is not always known. Improvements are also reported in commercial transport when lowered limits were established, although formal evaluations have not been carried out.

The reductions in crashes have occurred for drivers *at all blood alcohol levels.* Thus, in states that have reduced the limit from .10 to .08, crash rates have been reduced for drivers with high BACs as well as among drivers with BACs between .10 and .08. This reduction is likely due to a variety of factors, including increased media attention to impaired driving, a general sense that laws are stricter and enforcement more likely, and changes in norms surrounding changes in the law. Some safety improvements have occurred even in situations where enforcement of the lowered limits has been weak.

Misleading messages concerning legal limits

Current laws concerning blood alcohol limits may convey the message that drivers can operate safely until they reach the legal limit. Safety improvements might result from better public understanding of the nature of impairment. The public should understand that impairment begins with the first drink and that driving impairment is present even when overt behavioral signs of intoxication are absent.

Gaps in knowledge

While existing research can provide important guidance regarding laws, policies and practices related to low blood alcohol levels, significant knowledge gaps remain. Additional research would refine our current level of understanding. Remaining questions include a more detailed understanding of what particular performance impairments are most important in causing traffic crashes, what factors might help to mitigate the effects of alcohol, more details about the presence of alcohol in divers on the road at all hours of the day and days of the week, the role of alcohol in non-fatal crashes, etc.

Policy implications

While research indicates the impairing effects and increased crash risks of even low levels of alcohol, determining the best policy response is a social and political task. Each country tries to achieve the appropriate balance between reducing risks and permitting relative freedom of behavior. This balance clearly varies from country to country and evolves over time. In recent years in most countries the trend has been a steady reduction in BAC limits in response to the emerging science and the public intolerance of impaired driving.

Obviously, when dealing with relatively low BAC levels, it can be argued that other factors also increase driving risks, including fatigue and driver distraction. In addition, risks related to alcohol impairment occur in other areas besides driving, for example, operating boats and other recreational vehicles (such as snowmobiles).

It is an open question in the United States whether the benefits of further lowering legal limits outweigh the costs, including increased difficulty of enforcement. Improvements in safety might occur with better enforcement of existing laws and better public understanding of the risks of driving at BACs below the current legal limit. Clearly, however, lowering the limit below .08 in other countries has resulted in safety improvements. Additional research and analysis can provide more detailed understanding and inform policy decisions.

Discussion

The TRB workshop helped to bring together and synthesize a wide range of research findings regarding the nature of impairment at low BACs, the role of low BAC in traffic crashes, and potential policy responses to these findings. The full report on the workshop will be released by TRB and will be available through ICADTS. Other papers presented at T2002 present more detailed descriptions and updates of the research discussed at the workshop.