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Low Blood Alcohol Concentrations: Scientific and Policy Issues

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Low Blood Alcohol Concentrations: Scientific and Policy Issues

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Foreword

Over the past decade, considerable attention has been directed to drivers with high blood alcohol concentrations (BACs). Less is known about drinking drivers at the other end of the distribution: those with BACs below 0.08% or 0.05%. For example, to what extent do people with low BACs contribute to the alcohol-impaired driving problem? What factors or conditions enhance or mitigate impairment at low BACs? What are the implications for traffic safety, public information and education, enforcement, and the adjudication of offenders? What are the best strategies for dealing with drivers with low BACs? The workshop sought to answer these and other questions and to provide some perspective on low BAC policies.

Low Blood Alcohol Content: Performance, Safety, and Policy

KATHRYN G STEWART
Safety and Policy Analysis International

BACKGROUND AND STRUCTURE OF WORKSHOP

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? This workshop 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.*

The workshop covered several major topics:

- Experimental evidence of effects of low BACs on performance, including both laboratory testing of performance and testing on driving simulators
- The various factors that enhance or mitigate the effects of low BACs
- 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.
- The risk of harm associated with low BAC in various situations
- The effects of policies lowering BAC limits
- 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. The papers and responses are provided in full in this circular.

SUMMARY OF MAJOR CONCLUSIONS

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

*No specific definition of what constitutes “low” BAC was given for the purposes of the workshop, however, it was generally understood to apply to levels of .05 percent and lower.

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 their behavior is not obviously affected by alcohol. This situation makes individual judgements about fitness to drive unreliable. Similarly, it makes enforcement based on observation of impaired behavior 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 many other countries where random breath testing is permitted and widely used or where behavioral evidence of impairment is not required, the lack of behavioral signs of impairment is less problematic. In the United States, the legal structure entails a behavior-based enforcement system and thus makes enforcement more difficult than in countries that permit chemical testing more broadly. 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 constitutional 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, emphasizing 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.

Policy Implications

While research indicates the impairing effects and increased crash risks of even low levels of alcohol, it is a social and political question as to what the appropriate balance is between reducing risks and permitting relative freedom of behavior. Other factors also increase driving risks, including fatigue and driver distraction. It is an open question whether the benefits of 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. Additional research and analysis can provide more detailed understanding and further inform policy decisions.

SPECIFIC CONCLUSIONS: TOPIC BY TOPIC

Following are summaries of the more detailed and specific conclusions drawn by authors, discussants, and participants on each topic.

Laboratory Studies of the Effects of Low BACs on Performance

- Laboratory studies clearly indicate decrements in performance in some tasks starting with the very lowest levels of alcohol - .02 percent and even .01 percent in some cases.
- Not all performance measures are affected. Further research could help establish what aspects of impairment are most involved in crashes.
- 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.
- The research supports policies that have established low limits for alcohol.
- Some gaps in existing research remain, including the effects of alcohol on some behaviors, on judgement and on the propensity to aggressive behavior.
- It is important to increase public understanding of the impairing effects of low levels of alcohol in order to encourage changes in attitudes and driving behavior.

Laboratory Studies of the Effects of Low BACs on Driving Performance

- Despite the clear evidence of performance effects of low BACs, there are not always observable behavioral effects that have been well studied and established.
- Experiments are needed to identify observable behavioral signs of low BACs.
- Experiments are needed to provide more detailed information of the effects of low BACs on horizontal gaze nystagmus.
- The lack of well-understood behavioral cues of impairment makes it difficult for individual drivers or observers to make decisions about fitness to drive.
- Enforcement in the United States, unlike many other countries, is based on behavior cues rather than widespread chemical testing (i.e., through random breath testing). This situation greatly increases the difficulty of enforcement at all BAC levels.
- Many enforcement agencies do not make use of available technologies to enhance enforcement effectiveness in the absence of random breath testing. These technologies include passive breath sensors and preliminary breath testing devices.
- Existing technologies should be improved to enhance their ease of application. For example, passive breath sensors should be made more efficient and effective for use by patrol officers.
- Training should be provided to aid officers in the identification of suspects who have low or zero BACs and who may be under the influence of other drugs.

Factors that Enhance or Mitigate the Effects of Low BACs

- Positive reinforcement for sober performance seems to mitigate some effects of alcohol in laboratory studies.
- Warning subjects about the impairing effects of alcohol seems to provide some protection against impairment of performance of laboratory tasks.
- Practicing laboratory tasks under other impairing conditions (e.g., low visibility) seems to partially ameliorate performance decrements when impaired by alcohol.

Epidemiology Part I: Prevalence of Drivers and Drinkers with Low BACs

- The proportion of drivers on the road with non-zero BACs in recent US roadside surveys ranges from 14% to 19%, with substantially more drivers at low BACs and a steep decline in the proportion above .05%.
- Existing roadside testing research has primarily been carried out during weekends and nighttime hours. Additional research should examine the amount of driving that occurs at various BACs outside of these times of day and days of the week.

Epidemiology Part II: Crashes at Low BACs

- Previous crash case matching research that seemed to show a risk at low BACs less than the risk at zero BAC was in error. More refined methods and analysis have corrected this error and show steadily increasing risk at increasing BACs.
- Some analyses of crash risk suggest that risk increases exponentially with BAC while other analyses suggest that the relationship between risk and BAC is linear. The

difference between these two risk curves has scientific and policy implications. Further study and analysis should be carried out to describe the risk curve more accurately.

- Current estimates of alcohol involvement in crashes are not optimally accurate because of low levels of testing. Even in fatal crashes, testing is not universal, but the problem is particularly acute in non-fatal crashes. Testing of all drivers involved in crashes would enhance our understanding of the role of alcohol in crashes.
- The likelihood that apparently impaired drivers with low BACs have also used drugs should not be ignored. Routine drug testing of apparently impaired drivers with low BACs would help clarify the role of low BACs and the interaction with drugs.
- Young drivers are much more likely to be involved in crashes at low BAC levels. Enforcement efforts should be focused on enforcement of zero tolerance laws.
- The methodology of research examining the role of alcohol in traffic crashes should be strengthened, including increases in sample size and the application of laboratory findings to studies of behavior in real traffic settings.
- Alcohol (especially at high levels) is reported more frequently in severe crashes. This relationship may indicate the severity of errors made by drivers at high BAC. Other possible reasons include underreporting of alcohol involvement in minor crashes and the potentiating effects of alcohol on injury. More research is needed to improve understanding of this relationship.

Risk of Harm Associated with Low BACs

- Alcohol is also a risk factor in other activities, including boating. Enforcement and awareness campaigns aimed only at the boat operator should be broadened, since about half of boating-related drownings involve passengers, many of whom are impaired by alcohol.
- Careful examination is needed of the relative risk associated with alcohol, especially as compared with other impairing factors such as fatigue. Research should also take place examining the effects of fatigue and other impairing factors when combined with alcohol.

Low BAC Policies: Results and Mechanisms

- Support of enforcement of low BAC laws (.08, zero tolerance) is less than adequate to ensure maximum effectiveness. Media advocacy is one mechanism for raising awareness and enhancing support.
- Efficient, easy-to-use methods are available to carry out sobriety checkpoints with fewer officers. Sobriety checkpoints are one of the most effective ways of enforcing lower BAC laws.
- Refusal to take a BAC test is becoming very common. Laws and policies are needed to reduce the rate of refusals, including increased penalties for refusal and mandatory testing in the case of crashes. Current implied consent laws could be changed to reduce refusals.

- Enhanced enforcement and penalties for driving on a suspended license are needed, including vehicle sanctions.
- A tiered system of penalties for lower BACs may be effective, including less severe offenses at lower BACs and the establishment of enhanced penalties for speeding and other traffic offenses when alcohol is involved, even at relatively low levels.
- Establishment of lowered alcohol limits for drivers with prior impaired driving convictions has been found to be effective.
- While appropriate laws and vigorous enforcement are important, substantial changes in traffic safety are most likely to occur when social norms and standards of behavior change.

Implications of Research for Policy

- Public awareness strategies, including media advocacy, can be used to increase awareness of the personal risks associated with driving at low BACs.
- There is strong existing public and policy-maker support for low BAC limits for youth and commercial drivers. This support can serve as a basis for lowering BAC limits more generally.
- Existing laws should be enforced more vigorously. A variety of technologies and training can be used to enhance deterrence through increasing the threat of arrest and conviction for impaired driving.
- A variety of tools can be used to raise public awareness and concern about impaired driving in general, thus increasing public support for improved laws and better enforcement.
- The research community can serve as a powerful and credible voice in bringing about policy changes.

Laboratory Studies of the Effects of Low BACs on Performance

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The time available for presentations is brief, so I will begin by telling you what I'm going to tell you.

1. There are statistically significant experimental studies demonstrating that alcohol impairs driving related performance beginning at .01% BAC.
2. The effects of alcohol differ by behavioral area, both in the BAC threshold at which impairment appears and in the magnitude of impairment, if any.
3. Experimental studies in broadly defined areas such as cognition, perception and visual function exhibit a wide range of sensitivity to alcohol influence as a function of the specific experimental measures employed, suggesting that the descriptive rubric obscures the considerable divergence in behavioral functions required for the task employed.
4. Studies using simulator and on the road measures, divided attention, drowsiness and vigilance tasks have consistently reported that alcohol produces impairments at very low BACs.
5. Despite the heterogeneity of tasks used as experimental measures, over 50% of the studies examined in a 2000 literature review report impairment by .05% BAC.

The importance of selection of the appropriate experimental measures and design in examining the effects of low BACs on behavior will be illustrated by reference to a study by Moskowitz and Sharma (1974) examining peripheral vision. Failure of peripheral vision under alcohol is frequently cited as an important cause in automobile crashes, yet a literature review of peripheral vision studies under alcohol produced conflicting results. To resolve the contradictions, the following experiment was performed.

Figure A illustrates the apparatus in which peripheral vision was tested while the subjects were occupied with a central fixation light. The central light was presented under three conditions; either unblinking, blinking at a slow rate, or blinking at a fast rate. Signal lights were placed at 32 points in the horizontal visual field at six-degree intervals from 12 to 102 degrees on both sides of the fixation light. The subject had to detect the appearance of a one-second duration peripheral light stimulus. During the trials where the central light was blinking, the subject was required to count the number of blinks and report the total at the end of each 20-second trial. There were three alcohol treatments; placebo, 0.4, and 0.8 grams alcohol per kilogram bodyweight, which produced roughly zero, .045% and .09% BAC levels by calculation.

Figure B presents the percent of misses of the signal light in peripheral vision as a function of the peripheral angle, the BAC level and the central light conditions. The uppermost figure demonstrates that alcohol had no effect on peripheral visual signal detection when there was no demand for information processing in central vision. The middle and lower figures

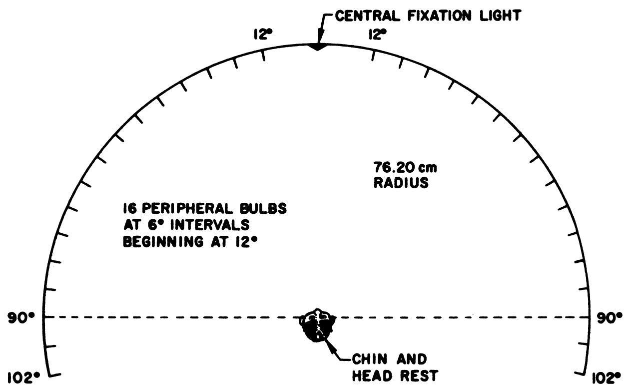


FIGURE A   Horizontal perimeter apparatus.

demonstrate that alcohol does impair peripheral vision as a function of the alcohol treatment, the central visual workload and the visual angle. The two alcohol treatments increased peripheral detection misses by 32% and 63% respectively under the slow blink condition and by 43% and 85% under the fast blink condition. There were also increased errors in counting the central blinking fixation light as a function of the alcohol dose and of the rate of blinking. If you look carefully at the placebo curves under the three blinking conditions, you will note that peripheral signal misses increased with increasing central blink rate even without the presence of alcohol.

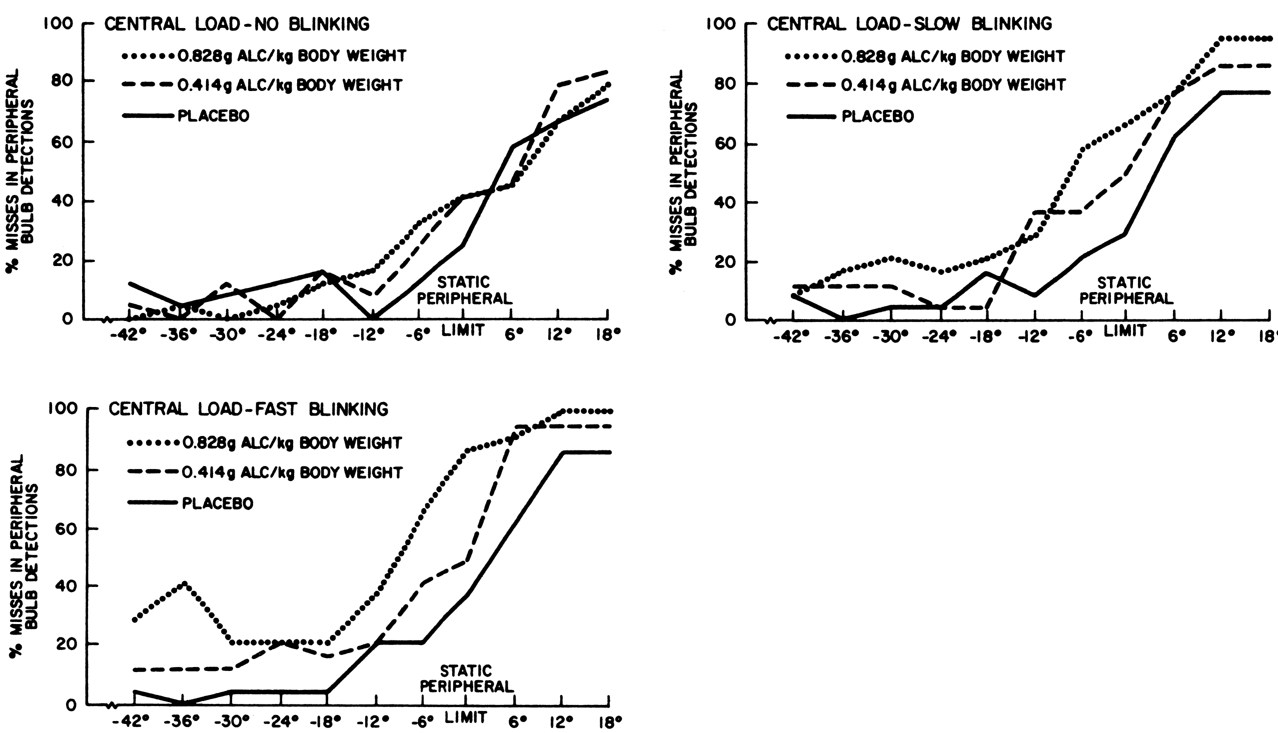


FIGURE B   Percentage of undetected peripheral light presentations.

This study illustrates some of the issues mentioned at the beginning of the paper. Under what category would you place this study? Cognitive or perceptual? Clearly, it is a perceptual function, yet whether or not alcohol has an effect on this perceptual function is an interactive function of mental workload, which is certainly a cognitive factor. This study suggests that the great variability in reports of peripheral visual impairment under alcohol is a result of the presence or absence of cognitive factors in the experimental situation of which some investigators were unaware. This study indicates that if you isolate the sensory function of peripheral vision, alcohol has no effect. Yet, in real world driving situations, it would be expected that very small levels of alcohol would produce very substantial impairment. Investigating the relationship between BAC level and impairment requires careful specification of the behavioral domain under consideration since the effects of alcohol vary greatly with behavioral area.

The conference organizing committee inquired as to the magnitude of impairment as a function of BAC. In this study, the relatively modest increase in central vision mental workload led to a large magnitude of peripheral vision impairment under low alcohol treatments. Making an assessment of the importance of a deficit produced by alcohol requires an estimate of the role of the examined behavioral function in actual driving situations. This study was initiated because accident investigations reported frequent failure of peripheral vision in driving. Analysis of crash epidemiology, as well as the experimental data, is necessary to assess the importance of a given behavioral variable on crash rate.

The organizing committee inquired as to the variability, both inter- and intra- individual, in impairment effects. There are actually few studies that have presented data on this issue. The study on peripheral vision found little variability between subjects in the magnitude of impairment. But the design of the study did not permit, as most studies do not, examining variations within a single individual’s impairment over time under the same dose. Note that examining variability of effects between individuals when performing complex tasks is often difficult. In many experimental studies, as in the real world, the demands of the task are often self-selected. When subjects are facing mental workload stresses, they often focus on different aspects of the task and ignore others. Under those circumstances, different subjects are facing different task demands and greater variability will result.

The introduction emphasized that behavioral areas differ greatly in their susceptibility to impairment by alcohol. The following figures are from a monograph by Moskowitz and Fiorentino (2000), reviewing the literature on the effects of low doses of alcohol on driving related skills. Following several random computer searches, we were able to obtain 109 studies that met the criterion for acceptance into the study, such as when the alcohol treatments were given, the accuracy of the BAC analysis, appropriate control treatments and statistical analysis, etc.

Figure C presents the lowest BAC at which the study found impairments under alcohol. Some studies reported impairments at BAC levels below 10 milligrams per deciliter, i.e. below .01%. Roughly half the studies exhibited impairment by .05%. The results are limited by the fact that few studies examined behavior at .01% or .02% levels. Determining the threshold of alcohol effects requires creating a drug dose curve, which few studies did. Thus, this figure is a minimum of what would be obtained were every study to perform a BAC drug dose analysis.

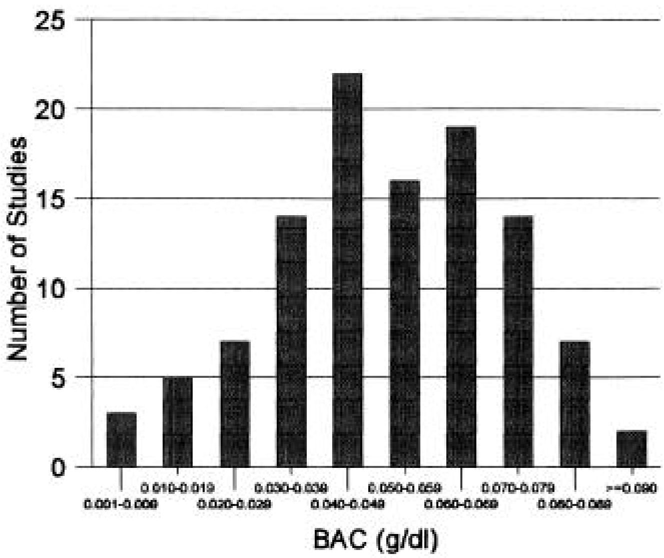


FIGURE C Number of studies reporting impairment (109), by lowest BAC at which impairment was found.

The 109 studies vary in the number of behavioral tasks examined. Many studies had more than one behavioral measure and many tested at several BAC levels. There were actually 556 combinations of tasks and BAC levels, and the results are reported in Figure D. Figure D indicates whether or not impairment was found for each behavioral test at each BAC examined. The number of impairments are represented by gray bars and the failure to find impairment is indicated by black bars. It can be seen that some behavioral tasks are impaired by .01% BAC. By the .03% to .04% BAC interval, the majority of behavioral tasks exhibit impairment. The last column marked with zero BAC represents after effects. Some behaviors clearly are impaired at very low BACs, whereas others are very resistant at even high BACs. However, it is not the behaviors which are unaffected by alcohol that result in crashes, but the behaviors that are impaired by alcohol.

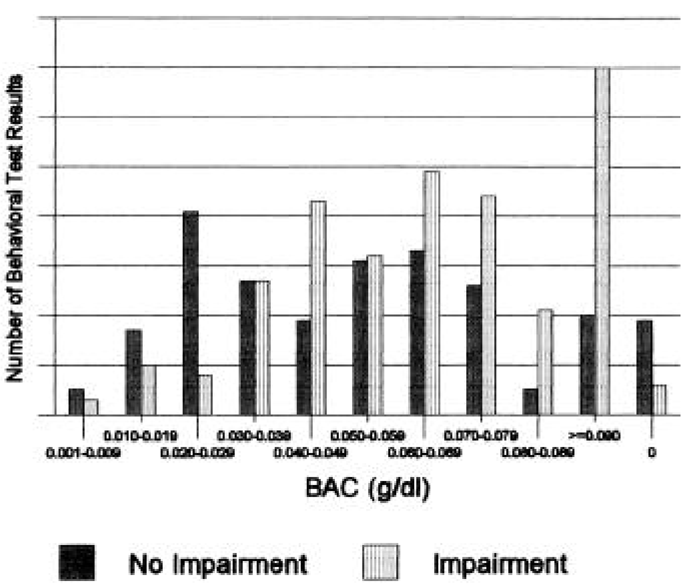


FIGURE D Summary of behavioral test results (556); aftereffects are reported at zero BAC.

The 556 behavioral task examinations were broken down into twelve behavioral categories. Membership in a category was determined by the original investigator's statement since the reviewers believed it difficult to reclassify a study without additional experimentation. As the peripheral vision study suggests, placement within a category is somewhat arbitrary, even more so if the experimental procedure has failed to isolate all the significant behavioral variables which determine the behavior under alcohol. Many studies characterized as belonging to a given behavioral area appear to have components of other behavioral areas. But without replicating the study and manipulating the variables to isolate these components, all that can be suggested is that the variability in results may be accounted for by the inclusion of behaviors of which the experimenters may not be conscious.

Figure E presents six behavioral areas; driving or flying, either in a simulator or on the road, divided attention, drowsiness, vigilance, tracking and perception. The first four areas report impairment earlier and more frequently than the latter two. This is in both the BAC threshold at which impairment appears and in the frequency with which impairment appears. When the driving/piloting category was examined in a literature review by Moskowitz and Robinson (1988), the simulator results were far more resistant to the effects of alcohol than here. Perhaps the advent of interactive driving simulators with greater mental workload requirements explains the increased sensitivity to alcohol.

The divided attention tasks similarly demonstrates early impairment by alcohol in the overwhelming majority of studies. Researchers define divided attention by the presence of two relatively simultaneous tasks. However, several of these divided attention studies tasks which are classified by logical definition, do not reflect a mental workload sufficient that the joint presence of the two tasks affects the performance on the tasks. In the peripheral visual vision experiment, the presence of a mental workload on central vision produced a decrement in peripheral vision even under the placebo treatment. There is a burgeoning literature, which demonstrates that virtually perfect time-sharing can occur in dual task performances under certain circumstances of training and task. [Schumacher, et al., 2001,]. When the divided attention or dual task situation is easily within the capability of the subject, it would likely be insensitive to alcohol impairment.

Drowsiness studies, measuring the tendency to fall asleep following alcohol treatments, and vigilance studies demonstrate impairment in the overwhelming majority of studies and at very low BACs. However, large variability in results occur in tracking and perception studies, suggesting that within these behavioral areas there are studies that differ in task character. For example, in tracking studies, adaptive tracking was more sensitive to alcohol effects than pursuit, compensatory, or critical tracking. No researcher has compared all four types of tracking in the same study to determine why there is such variation. Similarly, perceptual studies vary enormously. Tasks examined ranged from time estimation, auditory signal detection, visual search, anticipation time, to traffic hazard perception. Clearly, the rubric of perception is insufficient to adequately describe the diversity between tasks.

Figure F reports six additional areas. The first four; visual functions, cognitive tasks, psychomotor skills and complex reaction time exhibit the inconsistency in results found in the tracking and perceptual studies. Under the rubric of cognitive studies are tasks such as Sternberg's memory, code substitution, grammatical reasoning, mathematical processing, pattern discrimination, spatial orientation and card rotation to mention about one-half the cognitive tests. Clearly, "cognition" is not one behavioral area with respect to responding to alcohol.

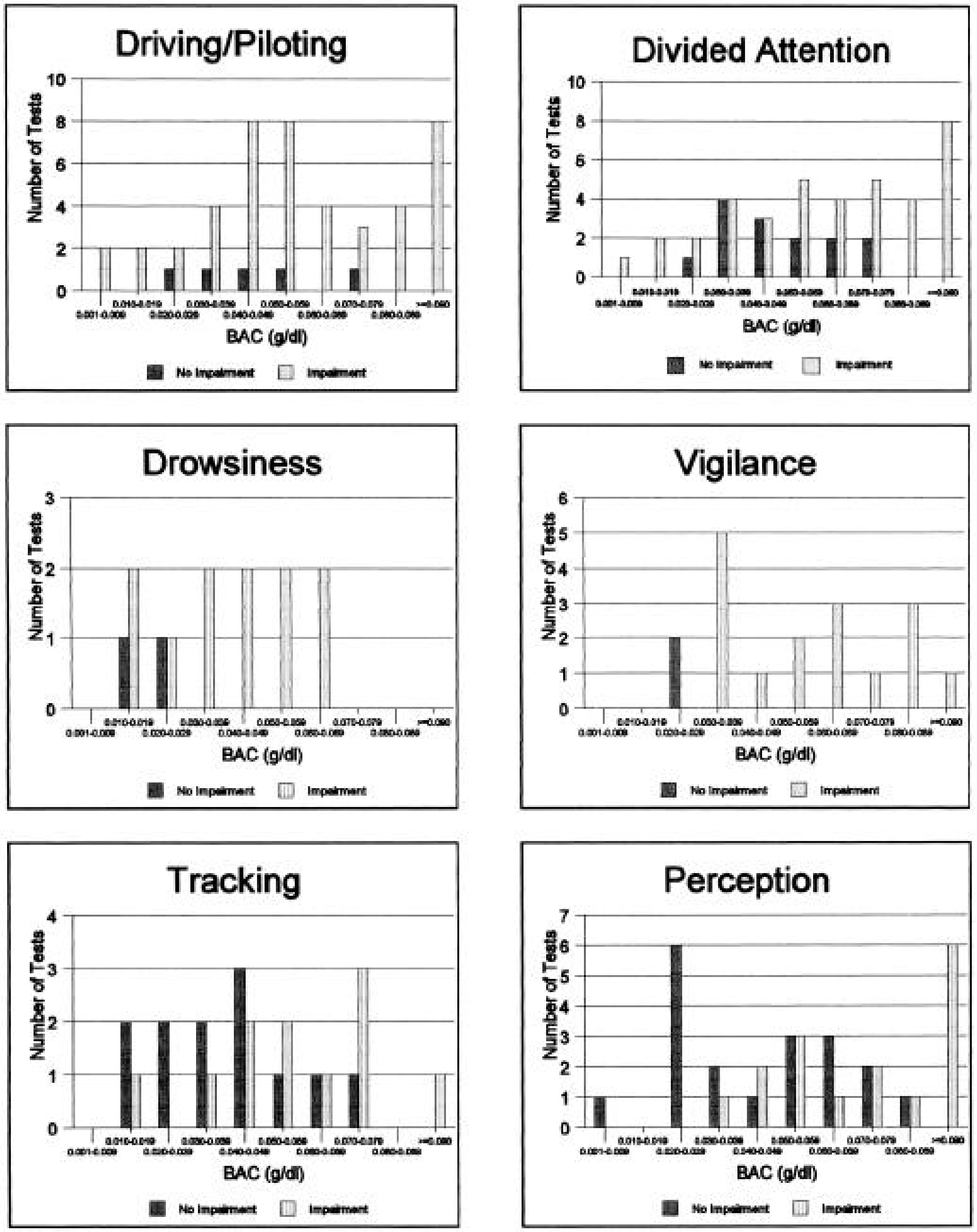


FIGURE E Behavioral test results, by behavioral area.

The last two areas presented in Figure F, simple reaction time and critical flicker fusion, on the contrary, show excellent consistency in their insensitivity to alcohol. The consistency reflects that these two areas are more clearly defined experimentally than such broad categories as cognition or perception. The uniformity of results is sufficient that we can advise investigators to avoid wasting time on these areas as a measure of alcohol effect, regardless of their possible use with other drugs.

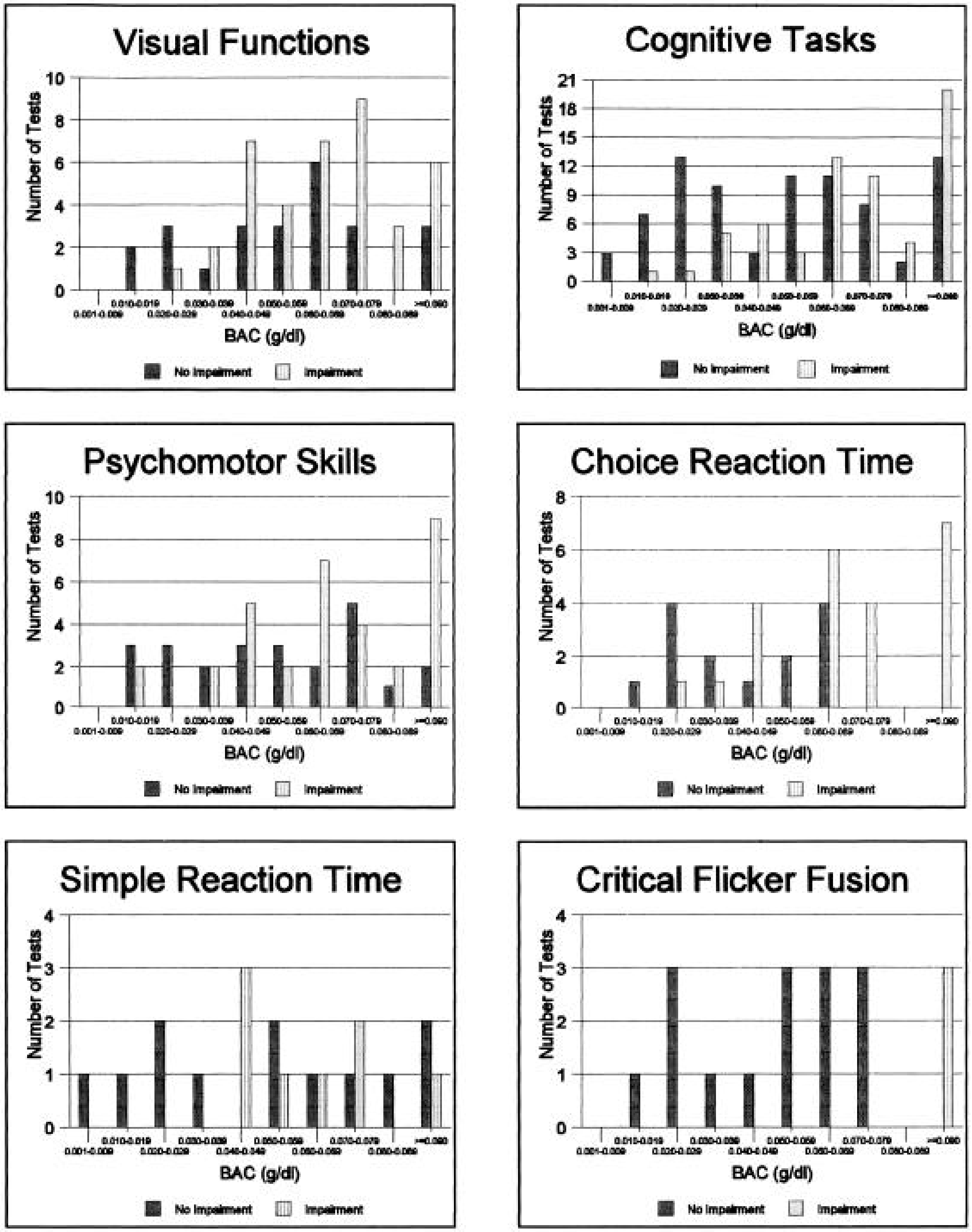


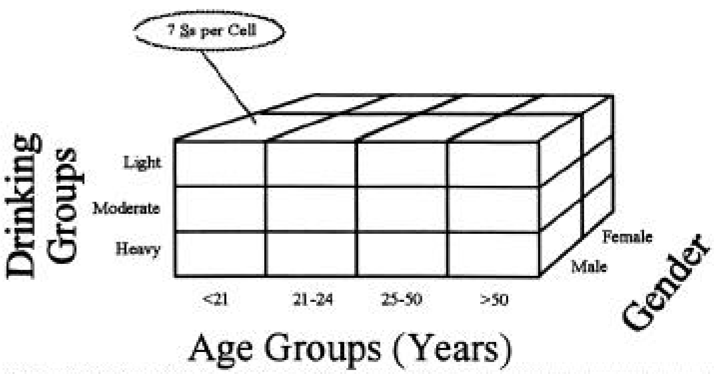
FIGURE F Behavioral test results, by behavioral area.

Despite the behavioral heterogeneity of reviewed tasks, it is clear that important driving related tasks are impaired by alcohol levels as low as .01%, that the majority of studies report impairment by .05% and that by .04%, the majority of tasks exhibit impairment. When future research further identifies the behavioral areas affected and not effected by alcohol, we can expect more frequent reports of alcohol effects at lower BACs.

It should be noted that not a single study examined either in the1988 or the 2000 reviews reported any improvement in performance at low BACs. Studies frequently failed to find impairment, but never did they find improvement.

The identification of behavioral areas sensitive to the effects of alcohol, to the extent that has been achieved, permits the researcher the tools necessary to examine subject characteristics and alcohol treatment variables that might modulate impairment by alcohol. Thus, Moskowitz, et al (2000) were able to examine how variations in age, gender and drinking practices effected impairment by BACs from .02% to .10%, utilizing a driving simulator and a divided attention task, which provided six and three response measures respectively.

Figure G presents the experimental design, an incomplete factorial design with 168 subjects categorized in four age, two gender and three drinking practice groups. Subjects in the moderate and heavy drinking categories were tested at .02% intervals on a declining BAC curve from .10% to zero, but light drinkers were only tested from .08% to zero. Subjects had two experimental treatments, one, an active alcohol administration and the other, a placebo administration on two counterbalanced days.



BACs for Post-Dose Tests:						
Light Drinkers		0.08%	0.06%	0.04%	0.02%	0.00%
Moderate and Heavy Drinkers	0.10%	0.08%	0.06%	0.04%	0.02%	0.00%

FIGURE G Experimental design.

The study utilized 3 response variables derived from the divided attention task and 6 variables from the driving simulator. As suggested by the literature review, the experimental tasks demonstrated great sensitivity and all 9 measures exhibited statistically significant impairment at all BACs beginning at .02%.

A greater magnitude of impairment would be expected had the study examined an ascending BAC curve. These tasks were sufficiently sensitive that they discriminated performance differences between groups within the age, gender and drinking practice categories under placebo. Of interest was the finding that heavy drinkers performed less well than light and moderate drinkers under placebo.

An impairment score was created for each subject at each BAC level by the difference between performance at that BAC level under alcohol and performance at the same time under the placebo treatment, using the pre-treatment, pre-tests as covariates. At no BAC level were there any differences in impairment as a function of age, gender or drinking practices. These surprising results hold true for roughly 90% of drivers since we did not test drivers under the age of 19 for legal reasons, nor over the age of 69. Furthermore, for ethical reasons, no subject was accepted who was suspected of alcoholism, nor any abstainers. This surprising result, within the limits of our categories, suggest that epidemiological studies reporting such differences should carefully consider the possibility of uncontrolled covariates and the existence of pre-alcohol treatment differences.

The literature review (Moskowitz and Fiorentino, 2000) examined after effects, i.e. when BAC returned to zero. Twelve studies examined aftereffects and produced 25 behavioral test results of which six reported impairment and 19 did not. Again, it is unknown to what extent the diversity of results are due to the selection of response measures. These studies are categorized as aftereffects rather than hangovers, which is a subjective reaction. Studies which reported performance impairment were either in a flight simulator or used the multiple sleep latency test, a commonly used test of tendency to fall asleep. Some of the variability may result from interaction with circadian effects, so that depending on what time alcohol is administered and when aftereffects are examined will influence results.

The literature confirms that the phenomenon of aftereffects exists, but which behaviors are influenced and under what conditions has been insufficiently explored.

The conference organizing committee asked speakers to comment on reports of disparate degrees of impairment during the ascending and descending BAC phases of alcohol consumption. Experimental literature supporting greater alcohol impairment during the ascending phase has existed since the 1920s and I know of no contrary findings. I can only contribute two studies to amplify this conclusion.

It should be noted that the phenomenon is an example of acute tolerance, i.e. an adaptation that occurs within a single drinking session. Another situation in which acute tolerance is exhibited is in the rate of drinking. The slower alcohol is consumed to a given BAC level, the less the degree of impairment. In a study by Moskowitz and Burns (1976), four sets of subjects were administered alcohol at a rate such that they reached peak BACs slightly less than .10% after completion rates of 15 minutes, 30 minutes, one hour and four hours. There was also a placebo control group. Subjects were tested at peak BACs and at .05% on the declining curve. As mentioned, the slower subjects drank, the lower their degree of impairment, although the slower the drinking, the greater the quantity consumed in order to achieve the desired BAC.

In 1973, Moskowitz, Daily and Henderson compared acute tolerance in the form of ascending and descending BAC curves in moderate and extremely heavy drinkers. The tasks utilized were body sway and hand steadiness. Although the heavy drinkers exhibited a greater alcohol tolerance to these tasks in their magnitude of impairment, they exhibited the same degree of acute tolerance, as did moderate drinkers. That is, the difference between ascending and descending BAC curves of impairment was as great for heavy drinkers as for moderate drinkers. Moreover, the differences between ascending and descending curves was obvious even at .02% BAC, the lowest level examined. Figure H illustrates some of the results.

The results suggest that chronic and acute tolerance have two different CNS sites and illustrate again the complexity of the analysis of alcohol effects. To summarize:

1. Alcohol produces impairment of behavioral functions critical for safe driving at BAC levels as low as .01%.
2. The magnitude of impairment increases with BAC level.

3. As the BAC level increases, more and more components of behavior are involved in producing a more complex set of impairments.
4. This last may explain why, although nearly all laboratory studies show a roughly linear increase in behavioral impairment with BAC, albeit with different slopes, nearly all epidemiological studies have shown an exponential curve of crash frequency with increasing BACs.
5. From the public policy point of view, there is no BAC level at which impairment does not occur. Setting a BAC driving limit as low as desired can be defended scientifically. It is however society's decision at what point they're willing to accept increased risk of injury to enjoy imputed benefits. There is no question that there are many accepted sports, such as football, skiing, bunjee and parachute jumping that are associated with large injury frequencies. Scientists have a responsibility to enable society to make a reasoned judgement regarding BAC driving limits or other countermeasures by explaining the risks of injury and the social and economic costs associated with those decisions. Uncovering and explaining how alcohol produces crashes and injuries is a necessary component of that educational program, as necessary for example, as uncovering the role of tobacco and nicotine in smoking related illness.

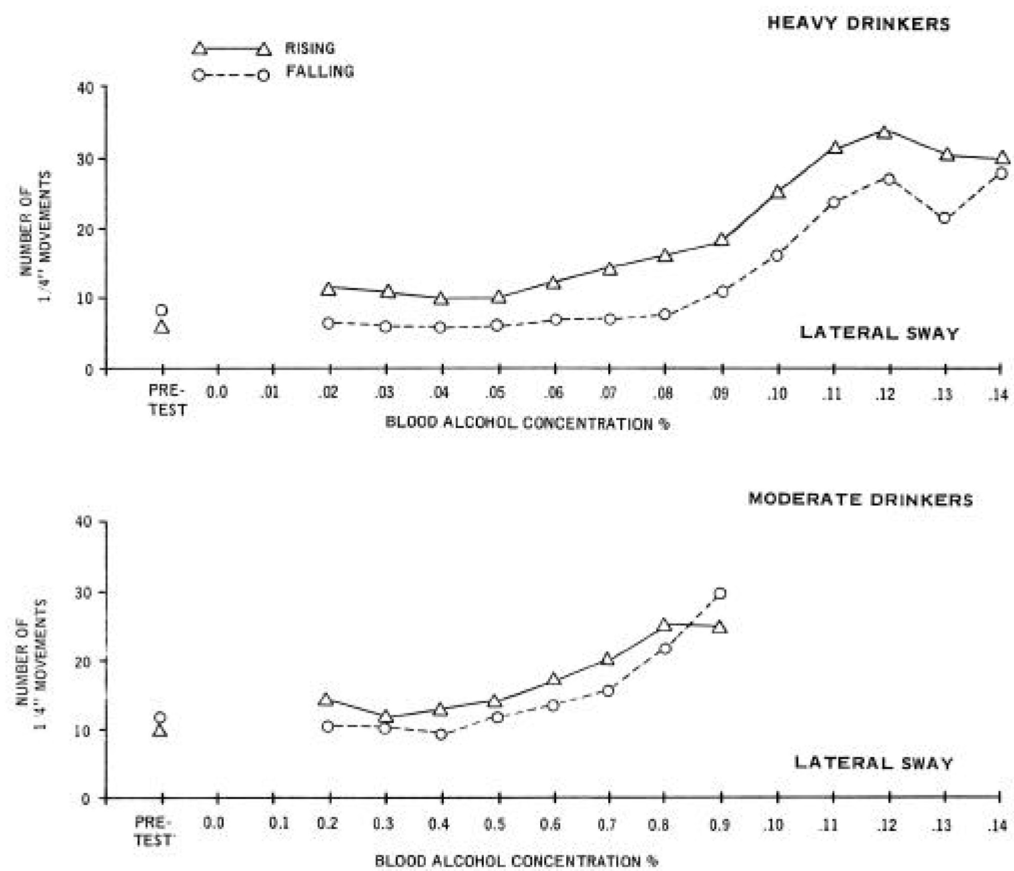


FIGURE H Rising and falling BAC performance of heavy and moderate drinkers on Lateral Sway.

There remains many insufficiently explored behaviors under alcohol, which can contribute to society's judgement about alcohol and driving. For example, there is extensive experimental and epidemiological evidence that alcohol increases aggression and violence, but no studies exist relating this to driving despite frequent references to the occurrence of road rage. Another inadequately studied area is the effect of alcohol on judgement. Drinking drivers are frequently described as speeding or attempting to pass in dangerous conditions, but few experimental paradigms exist to study this. Another area that deserves increased study for traffic safety is the well-established, experimental evidence that alcohol increases the likelihood of falling asleep, and reduces alertness due to drowsiness.

Finally, I would suggest a return to accident investigation studies, such as those performed in the 1970's, but now with the greater sophistication in understanding driver behavior and mechanisms of alcohol impairment that the past three plus decades have provided us.

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The Effects of Low BACs on Driving Performance

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INTRODUCTION

At blood alcohol concentrations (BACs) of 0.10%, drinkers exhibit observable signs of intoxication on at least some drinking occasions. At BACs of 0.15% or higher, they are obviously intoxicated unless they are chronic, heavy drinkers. Thus, there are behavioral signs of intoxication at moderate to high BACs, which the average observer can recognize. At low alcohol levels, however, the effects of alcohol on behavior are more difficult to detect. Furthermore, citizens may neither know nor accept the scientific evidence of significant impairment at low BACs.

States either already have or are expected to establish a 0.08% BAC limit for driving. Even lower limits may be enacted at some future time, and lower BACs mean that it will be more difficult to link impairment with observable behaviors. The 0.08% laws, together with laws establishing lower limits for youth and commercial drivers, are likely to create problems for the driving public's compliance with the law. Also, if neither driving patterns nor roadside behaviors are obviously impaired, there will be many enforcement problems.

From a drinker's perspective, if he does not *feel* intoxicated and if little evidence of alcohol influence is directly available to him, he may believe that he can drive safely. From the perspective of traffic officers, enforcement of driving-under–influence (DUI) laws often is a challenging task, and it becomes an extremely difficult task when neither a driver's conduct nor his driving pattern departs from the norm. This difficulty is apparent in data obtained in a Colorado field study. The most frequent roadside error of experienced traffic officers was the failure to arrest DUI offenders (Burns and Anderson, 1995). Presumably the errors occurred because the officers did not correctly assess alcohol impairment. Part of the current problem stems from the behavioral tolerance of chronic drinkers, but the problem will be extended to many more drinkers at low BACs.

EVIDENCE FROM THE SCIENTIFIC LITERATURE

Two literature reviews by Moskowitz and colleagues focus on the evidence of driving impairment at low alcohol levels. In the first, Moskowitz and Robinson (1988) examined the alcohol literature through 1985. Moskowitz and Fiorentino (2000) extended the work through 1997.

There were noteworthy developments during the period separating the two reviews. First, important new knowledge about alcohol emerged as a result of the increased sensitivity of performance measures, due in part to the advent of precise and reliable computer-based apparatus. Also, investigators began more frequently to examine performance at multiple alcohol levels. In many earlier studies, subjects were studied at a single BAC. With allowances for those differences, however, the findings from the two reviews are closely similar. The conclusion from both is that there is no threshold BAC below which impairment does not occur, and that some driving skills are impaired with any measurable level of alcohol.

In the more recent work, Moskowitz and Fiorentino (2000) assigned performance measures to thirteen behavioral categories: Aftereffects, Cognitive Tasks, Critical Flicker Fusion. Divided Attention, Driving Skills, Perception, Psychomotor Tasks, Reaction Time (Choice), Reaction Time (Simple), Tracking, Vigilance, Visual Functions, or Drowsiness. They reported large differences between the behavioral areas in terms of sensitivity to alcohol. For example, Critical Flicker Fusion and Simple Reaction, at one extreme, were judged to be essentially useless measures at BACs below 0.10%. At the other extreme, Driving tasks and Divided Attention tasks were the most sensitive measures. The literature includes reports of effects measured with these kinds of tasks at BACs below 0.01%.

The review notes a lack of research in several important areas. For example, although emotion, motivation, and judgment are known to affect driving performance, the effect of alcohol on these factors and the consequences for driving have not been studied. Also, the arousal-drowsiness continuum, which is highly relevant to driving, is affected by circadian rhythm, time-of-day, sleep status, and fatigue. Again, however, there has been little research attention to the impact on driving skills of alcohol in interaction with these variables.

A summary of the findings drawn from these two major reviews is cogently expressed in two statements:

- There is no BAC threshold below which impairment does not occur.
- Alcohol impairs some driving skills beginning with any significant departure from zero BAC.

Thus, the scientific literature provides strong evidence that alcohol impairment of driving-related skills occurs at low BACs. The literature does not, however, identify the specific *behaviors* which signal the presence of alcohol at impairing, but low, alcohol levels. Whether observations of drinkers at BACs below 0.08% can provide enough signs for the reliable recognition of the presence of alcohol remains an open question. At issue then is the enforcement of lower limits for driving, given that the statutes and policies of many jurisdictions restrict roadside breath testing. A parallel issue is whether citizens, lacking subjective cues in themselves or observable signs in their drinking companions, will be able to accurately assess their own or others' impairment.

EVIDENCE FROM DRIVING SIMULATOR DATA

Do overt, albeit subtle, behavioral signs of alcohol influence and /or alcohol-specific driving patterns occur reliably at low BACs? This paper offers a preliminary response to that question. The inquiry was directed by the null hypothesis that *what* and *who* is impaired do not differ as a function of BAC; i.e., that only the *magnitude* of impairment changes. The *nature* of performance deficits and the *characteristics* of impaired drivers were examined.

Sensitive and specific measures of performance were essential to pursue the questions of interest. Moskowitz and Fiorentino (2000) identified simulators as a source of potentially sensitive data. A subset of data was drawn from a driving simulator study (Moskowitz et al, 2000).

SCRI Driving Simulator

The Southern California Research Institute (SCRI) simulator is a computer-based instrument, which requires subjects to steer, accelerate and brake as they respond to the varying demands of driving the simulator in rural, suburban and urban environments. It presents wide-angle driving scenes on three large screens, has side- and rear-view mirrors, and provides realistic visual and sound feedback. As subjects drive, they also perform a visual search for peripheral signals as a secondary task.

During each drive segment, the system records measures specific to that particular driving environment. Additionally, throughout the entire drive it records three measures of driver performance which are common to all environments: number of off-road accidents, number of collisions with other vehicles, and number of times the posted speed limit is exceeded.

Rural drive. A straight road with occasional shallow curves, periodic cross traffic, and wind gusts simulates the demands of a rural driving environment. In this segment, speed and lane position measures are not confounded with other traffic factors.

Suburban drive. On a three-lane expressway, the driver attempts to maintain designated speeds (45 – 55 mph), to change lanes to pass other vehicles, and to avoid cross traffic and stalled cars. The roadway and traffic characteristics in this segment demand skillful steering and attention to speed control.

Urban drive. The posted speed limit for city streets is 45 mph. Pedestrians and traffic signals generate three unique measures: number of pedestrians struck, stops at red lights, and failures to stop at red lights.

Secondary task. Throughout a drive, the simulator operator monitors two diamond shapes displayed at the extreme right and left of the visual field. The shapes change at random intervals to produce 72 signals, which are a left arrow, right arrow, or a horn shape. Correct responses require activation of the corresponding turn signal or the horn button. Response times, number of correct responses, and number of response errors are recorded.

Analysis of Simulator Data

To address the questions at hand, six key measures (Table 1) were selected from a larger data set generated by the SCRI simulator in a study with 168 subjects (Moskowitz et al., 2000). The Reaction Time (RT) measure from the secondary task was selected, because it is expected to reflect the slowing of information processing by alcohol. The measure, Number of Correct Responses, was selected to capture attention deficits.

TABLE 1 Driving Simulator Measures

Detection of Peripheral Signals	Simulator Operation
Reaction time (sec.)	Speed deviation (mph)
Correct detections (no.)	Lane deviation (ft.)
	Collisions (no.)
	Posted speed exceeded (no.)

The selected simulator variables are measures of car control. It is unlikely that psychomotor skills will be sufficiently degraded at low BACs to directly affect these measures.

It is possible, however, that the euphoria and relaxed inhibitions associated with low to moderate intoxication will interfere with attention and result in increased speeding and risk-taking.

Moskowitz et al. (2000) report a detailed analysis of the experiment's entire data set, including measures from both the Driving Simulator and a Divided Attention task for placebo and alcohol sessions and 0.00 to 0.10% BACs. The data reported here are limited to the six selected measures and three BACs from alcohol sessions only. Also, note that the t tests of statistical significance include only those subjects with complete data..

RESULTS

Alcohol Effects at 0.00%, 0.04% and 0.08% BAC

The mean scores in Table 2 confirm that the magnitude of alcohol's effect is a function of BAC at 0.04% and 0.08%. Performance was poorer and more variable at 0.08% than at 0.04%, and at 0.04% than at 0.00%.

TABLE 2 Performance Measures with Placebo and Alcohol Treatments

	0.00%		0.04%		0.08	
	Mean	**Std. Dev**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Peripheral Signals						
RT (sec.)	2.87	.62	2.96	.62	3.12	.63
Correct (no.)	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 (no.)	4.2	6.29	5.8	9.46	9.7	12.26
Speed limit exceeded (no.)	4.4	5.11	9.2	8.99	12.1	10.52

Moskowitz et al. (2000) reported statistically significant impairment of these six measures at 0.08% BAC. The magnitude of the absolute changes in performance also reflects practical consequences for driving. RT, for example, was slowed on average by a quarter second compared to the pre-dose RT. A vehicle traveling at freeway speeds can traverse more than 20 feet in that length of time, a distance that could be a contributing factor to crash avoidance or crash occurrence. The average ¾ foot increase in lane deviation reflects a deficit in the fine maneuvers of stable steering. Five additional collisions and triple the number of speeding incidents are not trivial driving errors.

The six measures of driving performance were statistically significantly impaired at 0.08% as compared to 0.04% (Table 3). Between 0.00% and 0.04%, however, only three measures changed significantly (Bonferroni p adjustment).

Two car control measures, Lane Deviation and Speed Limit Exceeded, were significantly impaired at 0.04%. Mean lane deviation increased by approximately one-half foot. Although that statistically significant difference is not large in absolute terms, it is noteworthy nonetheless. Alcohol-impaired drivers typically allocate their reduced capacity to the continuous demands of steering. As a result, initial performance losses occur in other components of the driving task. This finding of a significant increase in lane deviation suggests a deficit in attention to steering even at a low BAC.

TABLE 3 Simulator Measures Paired t Tests

	0.00 – 0.04%			0.04% – 0.08%		
Performance Measures	**t**	**df**	**p**	**t**	**df**	**p**
Peripheral Signals						
RT (sec.)	3.02	164	.003	5.07	156	.000
Correct (no.)	-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 (no.)	2.95	166	.004	6.04	158	.000
Speed limit exceeded (no.)	8.43	166	.000	5.53	158	.000

Traffic officers frequently detect DUI drivers at 0.08% and higher as a result of their excessive speed. In a somewhat unexpected finding, at 0.04% subjects 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 increased number of collisions at 0.04% is not statistically significant. Practically speaking, however, an increase from slightly more than four collisions at zero BAC to almost six at 0.04% can be viewed as a negative consequence of a low BAC. In the opposite direction, the tenth-second increase in response time to peripheral signals , although statistically significant, probably is trivial in terms of consequences for driving.

In summary, the limited insights provided by an analysis of six measures from a driving simulator indicate that behavioral and driving signs of impairment at 0.08% probably will sometimes be recognized by trained observers, largely due to the magnitude of performance deficits. In California, where there has been more than a decade of 0.08% enforcement, the conclusion is supported by the fact that traffic officers regularly make DUI arrests at 0.08%. What is unknown, however, is the frequency with which they encounter drivers at 0.08% but fail to recognize the presence of alcohol.

At 0.04% BAC, the examined performance measures did not yield obvious signs of impairment or intoxication. It is questionable whether a lay observer in ordinary interaction with an individual at that alcohol level could detect the kind of attention deficits, which are believed to underlie lane excursions and speeding. On the other hand, traffic officers are highly skilled observers, and they may be able to detect alcohol influence on driving patterns if they are trained to accept lesser driving errors as evidence. Weaving, for example, which frequently appears in traffic reports as an observed driving error, suggests large vehicle excursions rather than the small deviations noted here.

As a practical matter, time potentially will limit police officers' observations of relatively small car control errors. To reliably detect such errors, it would be necessary in most cases to closely watch a vehicle over several minutes. Traffic congestion, as well as other enforcement responsibilities, however, often will preclude an adequate observation period.

Even when there is cause to stop a vehicle, a driver at 0.04% is unlikely to exhibit obvious behavioral signs of alcohol influence. Although slowed responses can be a key observation, the average slowing at 0.04%, as exhibited in the simulator's secondary task, would not be apparent even to a highly skilled observer.

Driver Characteristics

Knowledge of *who* is most susceptible to impairment at low alcohol levels may provide some detection cues. Note the widely held truisms on this topic; specifically, women are more affected by alcohol than men, young people become intoxicated more quickly than older people, and naïve drinkers are more impaired by alcohol than chronic drinkers. If women, young people, and inexperienced drinkers actually do display signs of alcohol at lower BACs than other drinkers, 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 in performance between the three alcohol conditions was calculated, and the extent of change 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 change for each measure appears in **bold** in the tables.

At both alcohol levels, men showed the greatest increase in excessive speed and in number of collisions. They also experienced a greater increase in impairment on the secondary task. Women displayed greater increases in speed and lane deviations. It appears that low levels of alcohol may have more dangerous consequences for men than for women.

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 (no.)	**-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 (no.)	**50.94**	32.61	**168.83**	104.93	**78.10**	54.53
Speed limit exceeded (no.)	**120.95**	95.81	**179.78**	164.33	26.52	34.99

The age variable offers potentially more useful information than gender. Interestingly, the relative change in performance was smallest on all measures for the oldest drivers (Group 4, ages 51 to 69 years). Although their performance at zero BAC is affected by the age variable itself, these subjects experienced less relative change with alcohol than younger subjects. In some instances, that may reflect more experience with alcohol. Also, risk taking may decrease with increased age, even with alcohol.

The greatest changes between alcohol levels occurred for 10 of 18 comparisons in the youngest subjects (Group 1, ages 19 – 20 years). In particular, very large percent increases in collisions and speeding demonstrate that these young people, who by reason of age are relatively inexperienced drinkers and drivers, become dangerous drivers with even small amounts of alcohol. Based on these data, the policy for traffic officers should be to investigate for alcohol influence, even in the absence of any behavioral signs, whenever youthful drivers are speeding or are involved in a collision.

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 (no.)	**-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 (no.)	**183.33**	81.58	**386.11**	177.66	71.57	52.92
Speed limit exceeded (no.)	**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 (no.)	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 (no.)	-1.27	27.15	139.92	81.54	**143.00**	42.78
Speed limit exceeded (no.)	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

The findings by drinking category do not conform to expectations, and they merit very cautious interpretation. It is important to first describe the method by which applicants were assigned to the three drinking categories. A quantity, frequency, and variability scale (QFV) of drinking (Cahalan, Cisin, & Crossley, 1969) was administered, and applicants' responses were the basis for assignments to Light, Moderate, or Heavy drinker categories. To insure distinct separations of categories, the scale was modified to exclude applicants if their responses placed them on the borderline of two categories. Also, very light and very heavy drinkers were excluded. The assignments to category were based on applicants' self-reported drinking behaviors. Although their responses from two separate administrations of the scale were examined for consistency, there was no additional method for checking applicants' veracity. Some applicants could have been categorized incorrectly, but the number is believed to be small.

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

TABLE 6 Relative Performance Change by BAC for Light, Moderate, and Heavy Drinkers

	Percent Change								
	0.00% – 0.04%			0.00% – 0.08%			0.04% – 0.08%		
	Light	Mod.	Heavy	Light	Mod.	Heavy	Light	Mod.	Heavy
Peripheral Signals									
RT (sec.)	3.31	.80	**5.07**	7.73	8.16	**10.17**	4.78	**7.31**	4.85
Correct (no.)	-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 (no.)	**53.41**	50.00	22.66	116.53	**171.00**	117.94	41.14	**80.67**	77.68
Speed limit exceeded (no.)	129.46	68.88	**136.40**	**197.26**	134.23	193.69	29.55	**38.69**	24.23

A number of the between-drinking category differences in percent increase are so small as to lack meaning. Of interest, however, is the lack of evidence in six measures of driving 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. That is, they were more slowed and they made fewer correct responses, relative to their sober performance. At 0.04% they had the largest percent increases in speed deviations and in times exceeding the limit, indicating they were more likely than the other groups to fail to attend to or possibly to care about speed control.

At 0.08% both moderate and heavy drinkers increased lane deviations by more than 60%. Moderate drinkers had the largest relative increase in collisions, and light drinkers in exceeding the speed limit. 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.

DISCUSSION

Data reported in the scientific literature demonstrate that impairment by alcohol begins with any departure from a zero BAC and clearly support 0.08% BAC (or lower) legal limits for driving. The enactment of lower limits, however, raises questions about compliance and enforcement.

In judging their own fitness to drive, the information available to drivers is knowledge of the amount of alcohol they have consumed and subjective awareness of intoxication. In fulfilling their enforcement responsibilities, police officers observe driving errors, stop a suspect vehicle, and then observe, interrogate, and administer roadside tests to obtain information on which to base a decision to cite, arrest, or release. If the officer observes little to no evidence of intoxication at low BACs, he may fail to recognize impairment.

This paper posed the following questions:

- Do observable behavioral and driving signs of alcohol influence occur reliably at 0.04 and 0.08% BACs?
- Are there differences between 0.04% BAC and 0.08% BAC in the nature of alcohol performance deficits, in their magnitude, or in both?
- Do the characteristics of alcohol-impaired drivers differ as a function of BAC?

Data from a driving simulator provided limited answers. The six measures that were examined differed in magnitude as a function of BAC. They provided no evidence of differences in the nature of impairment that would aid in the detection of alcohol influence.

In an effort to identify characteristics of drinkers who are most impaired by alcohol, the percent change in performance between zero alcohol and the two positive BACs was calculated for gender, age, and drinking category. The percent-change differences between men and women probably will not assist in the recognition of impairment. Nor do changes by drinking category provide information that will facilitate observation of impairment. On the other hand, the changes that occur with alcohol were found related to young age. Police officers, as well as drinkers under age 21 years, should take notice that youthful drivers are the most impaired by alcohol at low BACs.

RECOMMENDATIONS

The passage of laws establishing lower BAC limits for driving does not guarantee that the expected benefits for traffic safety will be realized. For positive effects, drivers must comply with and traffic officers must enforce the laws, but both of these requirements present considerably greater challenges than was the case with higher BAC laws. Activities in four broad areas are recommended:

- Driver education
- Traffic officer training
- Enforcement policy
- Research

Driver Education

A counterproductive consequence of the BAC-limit approach to alcohol-impaired driving has been the belief by some drivers that any BAC below the legal limit carries no liability for safety. At lower limits, that belief almost certainly will be reinforced by the lack of subjective awareness of alcohol influence.

The driving public needs to know what traffic safety professionals already know; their skills are impaired at low BACs before they can recognize changes in their own performance and before they feel intoxicated. Information and education campaigns will need to avoid simple admonitions about drinking and driving, focusing instead on the relationship of amount-of-alcohol and BAC and BAC and impairment. An important objective of educational efforts for both novice and experienced drivers will be to dispel the perception that there is no risk until the BAC limit is exceeded or the drinker is intoxicated.

Traffic Officer Training

Traffic officers have not been provided routinely with specialized training for enforcing 0.08%, zero tolerance for youth, or 0.04% for commercial drivers. If there is to be any degree of success in enforcing these or any other low BAC limits for driving, the alcohol enforcement training in police academy curricula and in classes for sworn officers will need to be augmented with low BAC instruction. Without appropriate training, it is unreasonable to expect traffic officers either to enforce the laws or to be effective witnesses at trial.

Policy

Enforcement of low BAC statutes will be facilitated if police department policies support the use of passive alcohol sensors (PAS) and preliminary breath testing (PBT) instruments. In the same way that agency policy establishes practices for other equipment, policies can also mandate purchase, officer training, and routine use of these instruments..

Data from a laboratory study suggest that the sense of smell is a less-than-perfect method for detection of alcohol (Moskowitz, et al., 1999). The PAS, which analyzes a sample of air captured passively near a driver's face, offers an alternative the "detection by nose" method. If the air sample contains alcohol, colors are illuminated on a light bar to indicate a range of BACs. Thus, the instrument functions as an alcohol detector.

Many police officers have confidence in their ability to smell alcohol, and they resist using a PAS. Officers' stated reasons for not using the PAS, when instructed to do so for SCRI research projects, have included the following:

- They believe they can smell alcohol without an instrument.
- They do not want to deal with yet another piece of equipment.
- They dislike the configuration of the PAS as a large, low power flashlight.
- They distrust the instrument's accuracy.

These are reasonable objections, for which there are potential remedies. Although the manufacturer appears resistant to design change, current technology offers the possibility of a smaller, more reliable instrument. Whether specialized training for police will lead to increased use of the PAS is the topic of a research project currently underway with NHTSA funding (Fiorentino, in-progress).

Police officers generally will abandon equipment or procedures that do not help them do their jobs. If, however, they find a sensor device enables them to detect alcohol when they might otherwise have missed it, their initial reluctance to use an instrument can be expected to diminish. At the present time, instruments and training are not widely available to traffic officers. Agencies should be encouraged to provide instruments and establish policies for their routine use, particularly if instrument design and reliability can be improved.

PBTs are accurate and reliable instruments, which offer the best available approach to recognition of alcohol-impaired drivers at roadside. Unlike the PAS, officers accept and use the PBT. Although there is a risk that reliance on evidence from a breath test will result in the release of drug-impaired drivers, the risk can be countered to some extent if all patrol officers are given basic drug training. Furthermore, that particular risk has to be weighed in terms of what is known about the prevalence of other drugs vs. alcohol.

Although the problems associated with driving-under-the-influence-of-drugs (DUID) should not be underestimated, the greater prevalence and the larger problem belong to alcohol.. . The recommendation here, therefore, is to routinely train traffic officers to use PBTs, to provide them with the instrument and the essential support of departmental policy, and to develop and maintain records of calibration and maintenance.

There presently is no uniform standard across jurisdictions concerning the admissibility at trial of PBT readings as either probable cause or substantive evidence. Defense attorneys regularly mount vigorous challenges to breath test evidence, including PBT readings. As occurred with the Intoxilyzer and other evidential instruments, however, when PBTs are widely used, the issue will be tested with cases that advance to each state's higher courts. Given the accuracy and reliability of the instruments, it is assumed that eventually the challenges will run their course, and PBTs will be essentially universally accepted.

Research

Examination of a subset of simulator data from a large SCRI studied yielded some limited answers, as reported in this paper, to questions about *how* and *whom* alcohol impairs at low BACs. The findings suggest that finer-grained, more sophisticated analysis of extant data sets to specifically address questions about low BACs may be productive.

The scientific literature contains scant information about behavioral cues at low BACs. There is a need to determine whether alcohol influence at low BACs can be reliably detected by observation or whether it requires measurement instruments. It is possible that some information could be gleaned from arrest reports, but controlled laboratory experiments are needed to answer this question. The Standardized Field Sobriety Tests (SFSTs) and any other candidate tests that can be identified need to be examined in carefully designed and rigorously executed experiments with subjects at BACs of 0.08% and lower.

Horizontal gaze nystagmus (HGN) is the most sensitive and reliable test for roadside use. Police officers rely on it, and defense attorneys challenge it. At the present time, however, data are not available to either support its widest application or to counter challenges to its admissibility.

SFST laboratory research (Burns and Moskowitz, 1977; Tharp et al., 1981) identified HGN as the best test for discriminating between BACs above and below 0.10%. There is a need for experiments designed to determine the BAC at which HGN first occurs on the ascending alcohol curve and the BAC at which it last occurs on the descending alcohol curve with careful attention to between-subjects and between-sessions variability.

Data to determine the onset and offset BACs for the *observation* of HGN can be obtained by using trained, experienced police officers as examiners. Laboratory conditions should simulate a range of roadside light conditions, typical of those in which officers examine suspects.

A separate question concerns the onset-offset BACs for *occurrence* of the phenomenon. Does the occurrence of HGN parallel the occurrence of impairment; i.e., do the eye movements that signal the presence of alcohol begin with any measurable BAC? HGN measurements obtained with a sensitive instrument can determine whether the jerking movements actually occur at very low BACs but with a magnitude too small to be observed at roadside.

Although not specific to low BACs, additional SFST research is needed. The DUI defense strategy is shifting from direct challenges to the tests to challenges to an officer's administration of them. In some cases, courts have refused to allow testimony about a defendant's test performance, because the officer deviated in some way from NHTSA guidelines for standardized administration or because the entire test battery was not administered.

The concept of standardization currently is mis-interpreted both in training and in courtroom proceedings. There are test elements that can and must be standardized; there are others that cannot be standardized, particularly in the walking and balance test. The lack of precise measurement instruments at roadside, individual differences, and environmental differences preclude total standardization. Courtroom arguments would be foreshortened if data were available to demonstrate the relative importance, or lack thereof, of minor deviations from NHTSA guidelines. For example, should officers' opinions based on observations of the Walk and Turn test (WAT) be dismissed, because a marked, straight line was not available at roadside? Was it necessary to dismiss cases in a Colorado community because One-Leg Stand (OLS) tests were conducted on sidewalks very slightly sloped to allow runoff of melting snow? Is the observation of HGN invalid if it is made when the suspect is supine on a gurney? Although it is unlikely that any of these conditions lead to officer error, there are no published data with which to answer the arguments of a DUI defense attorney.

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Low Blood Alcohol: Behavioral Impairment or Tolerance?

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INTRODUCTION

Why does a dose of alcohol cause so much behavioral impairment in some drinkers, and so little in others? Why does the same dose impair a drinker on some occasions but not on others? Many factors that might intensify or mitigate the impairing effect of a moderate dose of alcohol have been suggested. This paper describes experiments on the effect of alcohol on motor skills, and tests the impact of three types of factors commonly thought to affect the degree of behavioral impairment under alcohol.

Repeated exposures: Heavy drinkers, and those with alcohol-related problems, are known to show behavioral tolerance to blood alcohol levels that would result in gross impairment in social drinkers. Similarly, seasoned social drinkers usually show less behavioral impairment under moderate doses of alcohol than do naive drinkers. These sorts of observations have sometimes been attributed to adaptive physiological reactions that restore homeostasis under the drug. These reactions are assumed to strengthen with each dose, so that repeated exposures increase tolerance to the behavioral effects of alcohol (e.g., Kalant, 1975).

Motivation/expectancy: Researchers have occasionally noted that the behavioral effects of alcohol are extremely difficult to detect in social drinkers and alcoholics when intoxication is socially unacceptable and sobriety is advantageous (e.g., Langenbucher and Nathan, 1983). Similarly in the area of traffic safety, police spot checks of drivers have shown that behavioral assessments by skilled observers cannot reliably identify drivers with extremely high BACs (e.g., Jones and Lund, 1986; Wells et al., 1997). Goldberg and Havard (1968) long ago suggested that this was the reason for introducing Breathalysers, and for defining intoxication by blood alcohol measures, rather than behavioral criteria. Together, these sorts of observations have led to the proposal that drinkers who are motivated by the expectation of some favorable consequence for sober behavior will resist impairment in spite of the drug effect (Vogel-Sprott, 1992). The expectancy here refers to a learned relationship between two events. An expectancy tells us that if this occurs, then that will follow. For example ,"If I do this, that will happen." This information is carried in memory and functions to guide behavior in situations that are perceived to be similar. Numerous sources of expectancies have been identified. For instance, alcohol-related expectancies may be learned through first-hand experience with the drug, or by the receipt of credible information, or by observing other drinkers.

New learned skills: Numerous investigators have noted that skills to master a task are learned drug-free, but when a task is performed under alcohol, this practice may result in learning new skills to overcome impairment under the drug (e.g., Barrett, et al., 1989; Dews, 1962; Goldberg, 1943). These new skills then may help to mitigate the impairing effect of alcohol.

EXPERIMENTS

Our research program has tested the impact of these factors on behavioral impairment under moderate doses of alcohol. The experiments have been conducted with social drinkers, ranging in age from 19 to 25, and follow a standard procedure. Participants initially learn a task drug-free. Then they return to the laboratory for a series of drinking sessions conducted on different days, usually a week apart. On each session they complete a drug-free test on the task to provide a baseline measure of their sober performance that day. Then they receive a moderate dose of alcohol (0.62g/kg) and perform tests on the task at intervals during the 2.5 hour session. Blood alcohol concentration (BAC) rises and declines during this time. The peak BAC of about 70mg/100ml is under the 80mg/100ml legal definition of intoxication in Ontario, and occurs approximately 60 minutes after drinking commences. BAC declines to about 50mg/100ml by 140 minutes when the session concludes. The drug effect is measured by the difference between a drinker's test score under alcohol and his drug-free baseline test score. The intensity of the drug effect is examined on each test, and the measures from all tests also can be averaged to obtain an overall measure of the impairing effect of the dose during a session.

Repeated Exposures, Motivation/Expectancy

This procedure allows the first two factors to be tested within a single experiment. The development of behavioral tolerance to repeated doses is examined by measuring the drug effect when a group performs the task on successive drinking sessions. The effect of motivation to perform well is tested by another group of drinkers who also perform the task on these sessions, but receive a reward each time their test scores under alcohol are comparable to their drug-free baseline scores. Rewards used in the experiments are money or social approval, the verbal comment "good".

These experiments have been conducted with different motor skill tasks. The results of studies using a Tracometer task illustrate the typical findings (e.g., Beirness and Vogel-Sprott, 1984; Vogel-Sprott and Fillmore, 1993; Sdao-Jarvie and Vogel-Sprott, 1991, 1992; Vogel-Sprott, 1992). This task is designed to assess some skills involved in driving. Here a person uses a steering wheel to control a pointer that moves over a display area. The display contains a number of targets that are illuminated in random order. The goal is to hit the targets as quickly as possible. As soon as the pointer is aligned over the target, another one lights up. A set number of targets is presented on a test, and performance is measured by the time to complete a test. Figure 1 shows the change in test scores at rising and declining BACs during the first session (first dose) when one group (AR) is rewarded for maintaining a sober standard of performance and the other group (A) receives no reward or other consequence. Zero on the vertical axis represents the drug-free measure of sober performance. Impairment (slower performance) on a test is shown by a positive change from baseline. The horizontal axis shows the time during the session and the associated BACs. The difference between the groups in the overall impairing effect of the dose is seldom significant on the first dose. However the AR group tends to show somewhat less impairment on tests as BAC declines, and their impairment diminishes progressively on successive sessions. Figure 2 illustrates the performance of the groups on the fourth session (fourth dose). Now the AR group shows more tolerance to the impairing effect of alcohol on all tests around the blood alcohol curve. Their resistance to impairment is significantly greater than that shown on the first dose. In contrast, the impairment displayed by group A on the first and fourth dose shows no appreciable change.

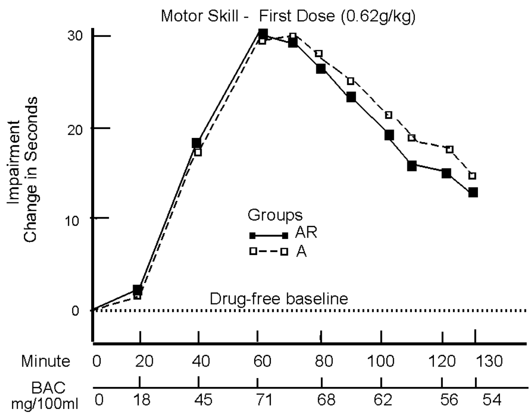

FIGURE 1 Typical changes in Tracometer performance under an initial dose of alcohol on 10 tests at intervals as BAC rises and declines in groups with reward (AR) or no reward (AN).

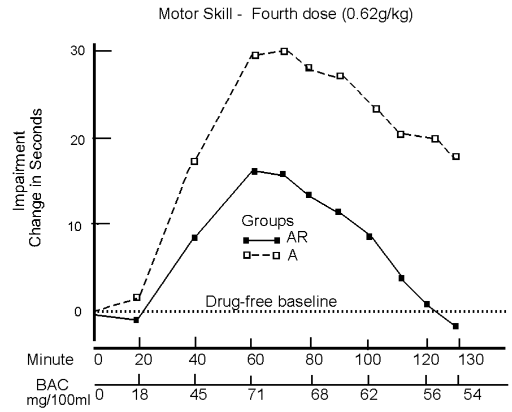

FIGURE 2 Typical changes in Tracometer performance under the fourth dose of alcohol on 10 tests at intervals as BAC rises and declines in groups with reward (AR) or no reward (AN).

It is probably not surprising that four moderate doses of alcohol are insufficient to generate any detectable behavioral tolerance in the A group. What is more remarkable is that the AR group develops so much tolerance in so few doses. Experiments including control groups that expect alcohol but receive a placebo and perform the task on repeated sessions display no significant change from their drug-free baseline scores, whether or not they are rewarded. A group that receives rewards randomly with respect to test scores under does not develop the tolerance shown by the AR group. Therefore it appears that the resistance to impairment depends on expecting sober performance to be rewarded. The persistence of the tolerance in the AR group also depends on maintaining the expectancy. If the AR group returns for additional drinking sessions where the reward is withheld so that the expectancy is not confirmed, their tolerance is lost (Mann and Vogel-Sprott, 1981; Zack and Vogel-Sprott, 1995, 1997).

Overall, the results are consistent with the proposal that when drinkers are motivated by the expectation of reward for sober performance, they will resist impairment.

Behavioral Conformity

This expectancy interpretation also fits notions of social conformity. People usually adhere to standards of behavior that match the social norm. The motivation here is the avoidance of criticism or other forms of social censure, and the expected reward is inferred from the absence of these noxious events. Some experiments using this motivation/expectancy training procedure have tested the effect of alcohol on motor skills (Zack and Vogel-Sprott, 1995, 1997). This work has shown that when sobriety under alcohol is the approved standard, drinkers conform by resisting behavioral impairment. Conversely, when the accepted norm is intoxication, drinkers conform by displaying considerable behavioral impairment. Adherence to these norms is remarkably persistent, and occurs even when drinkers expect alcohol but receive a placebo. It seems that whether extreme impairment or tolerance is displayed under alcohol depends on which type of behavior is expected to match the socially desirable standard.

New Learned Skill

When a task is repeatedly performed under doses of alcohol, the effects of task practice and alcohol are confounded. It is not possible to know if some skill is being learned through practice that might contribute to resisting impairment. Task practice would have to be separated from alcohol in order to determine whether the acquisition of new skills to overcome impairment contributes to tolerance. One way to do this is to provide drug-free task practice in overcoming environmentally-induced impairment that resembles the effects of alcohol on the task. After skill to overcome this type of impairment has been learned, its transfer can be tested to determine whether it increases resistance to impairment when the task is performed for the first time under alcohol.

This possibility has been investigated by providing drug-free practice on the Tracometer in an environment that impaired performance by reducing the visibility of the targets and making tracking extremely difficult. This creates a situation somewhat akin to driving in a fog at night, and slows performance in a fashion that resembles the impairing effect of alcohol on the task (Easdon and Vogel-Sprott, 1996; Zinatelli and Vogel-Sprott, 1993). Two groups first learned the task drug-free, in the standard environment. To confirm that the groups did not differ in sensitivity to alcohol at the outset of the experiment, they received a small dose of alcohol and performed one pretreatment test on the task at a rising BAC of 50mg/100ml. Then they returned for additional drug-free practice sessions where an Experimental group practiced under environmentally-induced impairment, and controls continued to practice the task in the standard environment. Figure 3 illustrates the performance of the groups during this drug-free practice period. It shows that the environmental conditions under which the Experimental group worked initially impaired (slowed) their performance, and the gradual improvement as practice continued indicates the development of new learned skills to overcome this impairment. In contrast, the Control group practicing in the standard environment shows little change. The scores of the groups before, and again after this drug-free learning period do not differ.

After this drug-free learning treatment, the groups returned another day to perform the task in the standard environment, for the first time under alcohol. Both groups were rewarded for test scores under alcohol that matched sober baseline scores to ensure that they were motivated to perform as well as they could. The results are shown in Figure 4A. Compared to the Control group, the Experimental group shows more resistance to impairment on all tests around the blood alcohol curve.

Figure 4B shows the impairment each group displayed at a BAC of 50mg/100ml before, and again after, the special drug-free learning treatment. The development of drug tolerance is customarily identified by a reduction in the initial intensity of the drug effect. The drug-free training administered to the Experimental group developed behavioral tolerance to alcohol, whereas no significant reduction in impairment is evident in the Control group.

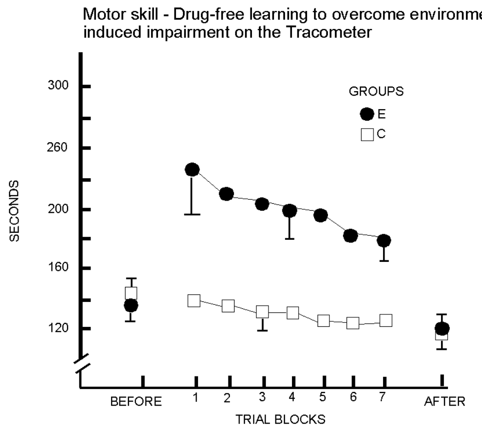

FIGURE 3 Performance on blocks of four practice trials under environmentally-induced impairment (Group E) or standard control conditions (Group C).

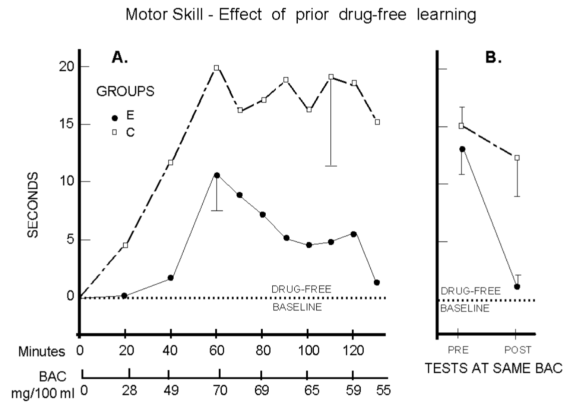

FIGURE 4A Post-learning change in performance of Experimental (E) and Control (C) groups on trials under .062g/kg alcohol. FIGURE 4B Pre- and post-learning tests at a rising BAC of 50mg/100ml.

Both groups were motivated by the expectation of a reward for performing well under alcohol. The Experimental group only differed by having already learned skills to overcome impairment. So it seems that motivation to perform well, coupled with the skill to do so, can result in tolerance the first time a motor skill task is performed under alcohol. And if these skills have not been acquired in advance, the gradual increase in resistance to impairment when a task is performed under repeated doses of alcohol may reflect the development of this learning.

Expected Outcome of Cognitive Performance

These conclusions raise an interesting question about tasks that involve no learned motor skill. Resistance to alcohol impairment of such tasks could not be delayed by the need to acquire new motor skills, so it could be shown immediately, under a first dose of alcohol. All that may be needed is the expectation of a favorable outcome for sober performance.

Some tasks that assess cognitive processes without involving any learned motor skills have been used to test this possibility (Fillmore and Vogel-Sprott, 1997 , 1999, 2000; Fillmore et al., 1998; Mulvihill et al., 1997; Vogel-Sprott and Fillmore, 1999). The findings all point to the same conclusions, and can be illustrated by the results on a Rapid Information Processing (RIP) task (Fillmore and Vogel-Sprott, 1997). This a computerized task. An individual is presented with digits, one at a time on a computer screen, and merely presses a button whenever a particular sequence of digits is detected. The rate at which digits are presented speeds up slightly each time a sequence is correctly identified, and slows down if a sequence is missed. The average number of digits presented per minute measures the rate of information processing. One group in the experiment served as a control, and performed the RIP task with no alcohol. The other two groups performed the task under alcohol. The only difference between the alcohol groups was the presence or absence of a reward for a sober standard of performance (i.e., a drinker's drug-free rate of information processing).

Figure 5 shows the change in digits processed per minute on tests during rising and declining BACs under a first dose of alcohol. Impairment, (slower information processing) is indicated by a negative change from the drug-free baseline. The group (A) performing without reward shows impairment. Information processing is slowed. But the group (AR) rewarded for sober performance shows no significant impairment. It does not differ from the drug-free control group (PL). The results suggest that cognitive performance is characterized by swift resistance to alcohol impairment. It can occur under a first dose of alcohol. All that is needed is the expectation of some reward for performing well.

Expecting Impairment

Other alcohol-related expectancies may also be important. Some research using a computerized Tracker task has shown that the amount of impairment a drinker expects from a dose of alcohol can influence behavioral impairment (Fillmore and Vogel-Sprott, 1996). This task presents a moving target on a computer screen and a person moves a mouse that controls an on-screen circle with a cross-hair. The goal is to keep the cross-hair over the target as long as possible. The percent time on target during a test measures performance.

After training on the task, participants in these experiments rated the amount of impairment on the task that they expected from drinking two beers. The ratings showed they expected only slight impairment. Before the task was performed under alcohol (0.56g/kg) one group (AE) received information leading them to expect that this moderate dose could cause considerable impairment on the task. The other alcohol group (A) received no information. A control group (PL) received no information or alcohol.

Figure 6 shows the performance of the groups on tests during rising BACs. Impairment (less time on target) on a test is indicated by a negative change from the drug-free baseline. The AE group led to expect considerable impairment displayed more behavioral tolerance to alcohol than the A group expecting no appreciable impairment. It appears that drinkers warned to expect considerable impairment under alcohol attempted to prepare themselves to withstand it. In contrast, when mild trivial impairment was expected, there was no anticipatory preparation, and the disrupting effect of alcohol was more intense. This might be called an example of forewarned is forearmed.

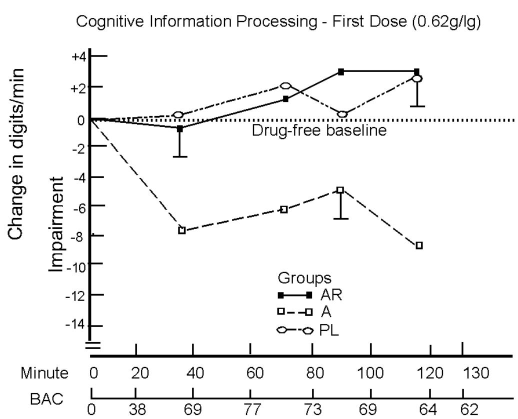

FIGURE 5 Speed of information processing in groups under a placebo (PL), or alcohol (A), or alcohol with reward for unimpaired performance (AR).

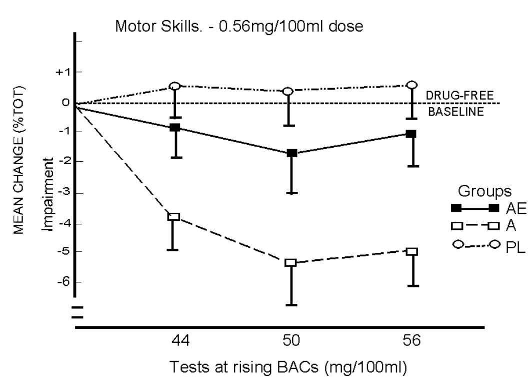

FIGURE 6 Pursuit Rotor performance of groups under alcohol (A), or alcohol plus the expectation of considerable impairment (AE), or placebo (PL).

CONCLUSIONS

The results of this research indicate that the degree of behavioral impairment under low and moderate BACs is not solely determined by the alcohol content in the blood. Less impairment in motor skills is shown by drinkers motivated by the expectation of some advantageous consequence for sober behavior.

Alcohol impairment of motor skills is also reduced by learning how to overcome conditions that impair task performance. Although these skills may develop when a task is repeatedly performed under alcohol, they also may be acquired without any drug exposure, through drug-free task practice under conditions that induce impairment resembling the effects of alcohol.

When drinkers are forewarned to expect alcohol to cause appreciable behavioral impairment, they make some anticipatory preparation that allows them to better resist these drug effects.

Implications

Laboratory research identifying factors that reduce behavioral impairment under low and moderate BACs provide a foundation for applied studies evaluating their policy implications. The findings reviewed in this paper suggest some new initiatives in the area of public education and information that aim to develop safer behavior under alcohol.

Given that impaired performance under low and moderate BACs increases the risk of accidents and other harmful events, public education programs are naturally designed to alert drinkers to these negative consequences. However, the programs could go a step further to promote safe behavior by informing the public about the positive consequences of a sober standard of performance. Sobriety as the approved norm may be fostered by emphasizing the desirable personal and social incentives for resisting behavioral impairment under alcohol.

It seems that drinkers may not expect BACs below the legal definition of impairment to cause any appreciable behavioral impairment. Information to correct and change this expectancy could be helpful in promoting safety. Forewarning drinkers to expect impairment at these lower BACs may aid them in resisting it, and making better informed decisions about what activities may be hazardous to undertake.

Defensive driving programs develop skills to avoid accidents under inclement weather and other impairing conditions. Such programs have not intended to develop skills that reduce the impairing effect of alcohol. But they may be beneficial in this regard, because drug-free learning of motor skills to overcome environmentally-induced impairment apparently can transfer and assist drinkers to resist alcohol-induced impairment. If this proves to be the case with defensive driving programs, their promotion as essential might contribute to reducing the risk of alcohol-related driving accidents

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Comment on "Effects of Low BACs"

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INTRODUCTION

The three papers presented this morning summarize laboratory studies examining the effects of BAC on performance. The results indicate:

1. Impairment can be found 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, there is no differential alcohol effect as a function of age.
4. Laboratory studies suggest a linear increase in impairment with increasing BAC whereas epidemiological studies suggest an exponential increase.

Each of these laboratory findings can be compared with motor vehicle crash data. This afternoon, the crash data utilized will be drawn from epidemiological case/control studies most notably Grand Rapids. This morning, the crash data will be drawn primarily from FARS. The analytical approach will be induced exposure.

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 or all drivers at .00% BAC (after Clayton, 1977).

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

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 factors of 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."

RISK

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

	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
GES	1.00	0.91	0.89	1.13	1.46	1.89	5.70	17.11	23.62

The paragraphs below compare the data shown in Tables 1 and 2 with the laboratory findings.

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 ($\div^2 = 1.66$, 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 ($\div^2 = 14.49$, $p<.001$ with 1 df).

In summary, the current data for fatally injured drivers using induced exposure methods, indicate a statistically significant increase in crash risk beginning at .02%. While increased risk at .01% appears likely, the increase at .01% was not statistically significant.

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.

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.

This finding can be examined in the present data by: excluding the youngest and oldest age groups; normalizing each remaining age group to a risk of 1.00 for .00% BAC; and plotting the resulting risk levels. This plot for age groups 21-24, 25-34, 35-49 and 50-64 is shown in Figure 1. Essentially, the Figure shows four nearly overlapping lines. That is, consistent with the laboratory findings and using each age group as its own control, the present induced exposure risk data suggest no “differential” effect of alcohol as a function of age.

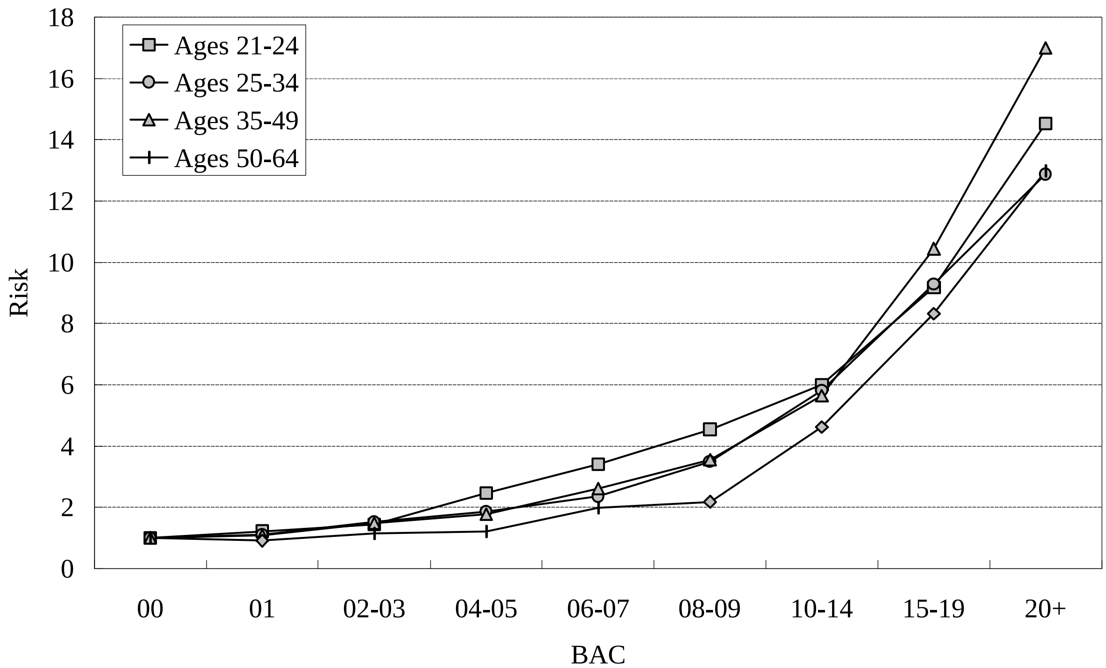

FIGURE 1 Risk for each age group, driver fatalities, 1987-99 (N=137,326)

Laboratory studies suggest a linear increase in impairment with increasing BAC whereas epidemiological studies suggest an exponential increase: Figure 2 plots the data shown in Table 2. The diamonds indicate the induced exposure results from FARS. Note that the right side of the X-axis indicates grouped data. When these categories are spread to the right along the X-axis at the appropriate distances, the induced exposure results indicate an approximately linear risk function.

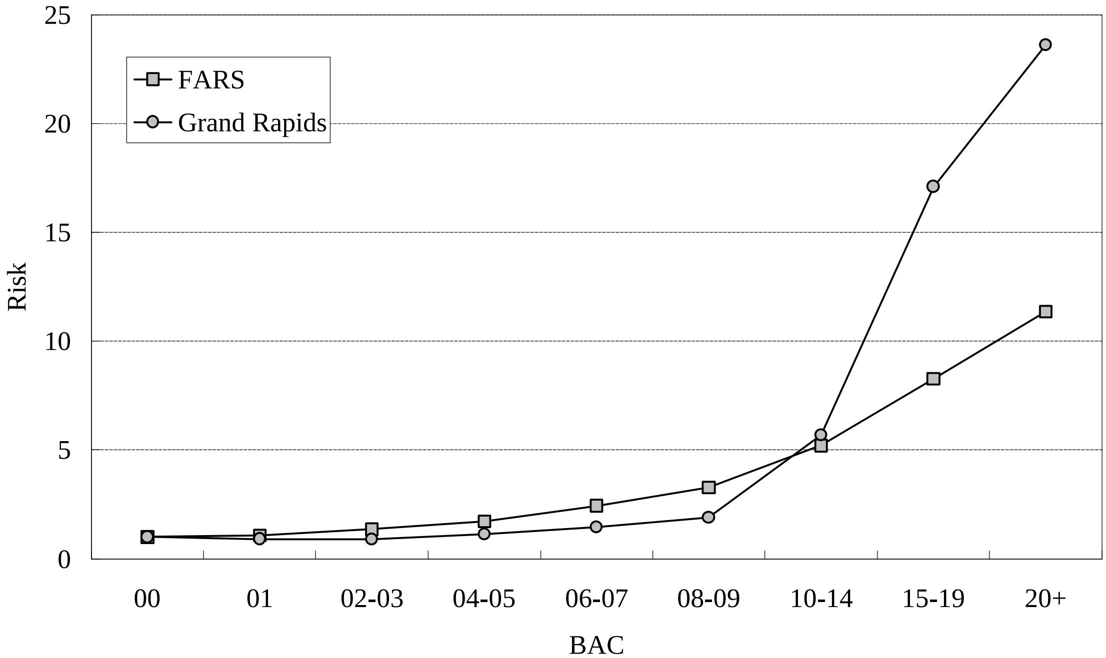

FIGURE 1 Risk by BAC Driver Fatalities 1987-99 (N=192,282)

Our primary epidemiological data set is Grand Rapids: The squares in Figure 2 show the Grand Rapids data. The plot for Grand Rapids is below the induced exposure plot for all BAC levels up to .09%. It crosses the induced exposure plot at about .10% BAC and then moves sharply higher. While spreading the X-axis lessens the exponential character of this plot, it by no means eliminates it. Grand Rapids is essentially exponential while induced exposure, consistent with the laboratory findings, is essentially linear.

Why do the epidemiological results differ from both induced exposure and the laboratory? Epidemiological 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, ten or one hundred and ten 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. That is, 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 values that are actually less than 1.00 for BAC levels which are positive yet low; higher than 1.00 for high BAC levels; summing to an overall risk level of 1.00. Any such downward bias for low BACs in epidemiological studies would have the effect of accentuating an exponential risk by BAC function.

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%. Alternatively, if the relationship is exponential, then it follows that lowering the BAC from .15% to .14% will produce the greater reduction in risk.

CONCLUSION

There is clear correspondence between the laboratory findings and driver fatal crash risk. Low BACs do increase risk. Increases in crash risk by BAC do 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 epidemiological studies. If linear, it becomes even more important to address low BACs in any comprehensive effort to reduce alcohol related crashes.

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Comment on “Effects of Low BACs”

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LABORATORY STUDIES

The paper by Herbert Moskowitz, “Laboratory Studies of the Effects of Low BACs on Performance,” is a strange creature which is a literature review mixed with rather detailed reports of a number of experiments.

As always a joy for me to read Herb´s reports since he always confirms my own thoughts. And since he does so, it is difficult for me to find the weak points.

Well, I think that his emphasis on semantics – whether a test or a study is within the field of cognition or perception etc. – seems to me to be superflous. Even if you leave this discussion out it should serve as a very good guide as to sensitive measures. His passion for gourmet menus shows up here – this is a gourmet menu for the student of performance impairment. It should also serve well for the legislative committee which is considering new legal limits. It very clearly demonstrates that there is a lot of new evidence to the fact that any departure from zero BAC will lead to impairment of relevant faculties.

I appreciate the tentative explanation for the exponential curve of crash frequency when nearly all laboratory studies show a linear increase in behavioural impairment with BAC.

For 30 years I have had a hard time fighting off the hordes of people who claim that small amounts of alcohol actually improve performance. Herb permits me to bury this myth. His report also makes me look forward with great anticipation towards the final report of Grand Rapids à la Moskowitz.

A couple of questions: Nothing is mentioned about motivation regimes. I have frequently found that when you pay subjects for performance and when you have several measures i e when they are payed for speed and for accuracy concurrently, this always creates strategies to maximize the monetary reward. If regimes like this have been used, they might have influenced the results.

As for recommendations I agree wholeheartedly with Herb in wishing to see more research on the effects of alcohol on judgement and on road aggression and the sedating effects of alcohol. However, before we bury the myth of improving effects of alcohol on performance, it is necessary to carry out a study which explicitly sets out to find out whether such effects actually exist.

EFFECTS ON DRIVING PERFORMANCE

The paper by Marcelline Burns and Dary Fiorentino, “The Effects of Low BACs on Driving Performance,” is another very valuable guide for the student of the impairing effects of alcohol on driving performance. To some extent, it overlaps the Moskowitz paper.

The authors talk a lot about the practical implications for law enforcement, some of which are not relevant in other jurisdictions like where random testing is possible. In their discussion about enforcement problems they fail to discuss alcohol tolerance and that alcohol tolerant drivers may go undetected until they have a crash since only in demanding situations will their impairment show up. By the way, before we introduced mandatory daylight running lights and automatic lights, the prime cue for the police was dark headlights.

Marcy and Dary report some rather unexpected findings – men being more impaired than women etc. This makes you wonder about possible explanations in terms of motivation strategies. In a number of pilot studies where subjects have been paid for speed and punished with payment reductions for crashes or missed signals etc, subjects quickly realize that there might be money to be made by sacrificing one measure for the other. We have also seen that men have had a tendency to favor speed for other measures. The paper does not mention anything about motivational factors.

We have also seen a tendency for men to be more aware of the fact that they are in a driving simulator and that therefore a crash has no real consequences. This has made them more willing to take “risks”.

The authors also find that moderate drinkers have the largest relative increase in collisions and light drinkers in exceeding the speed limit – could there be an interaction between gender, drinking category and impairment on the different impairment indicators?

Thoughts: I share the concern that as legal limits are lowered it becomes more and more difficult to detect the low BAC driver in traffic. This could possibly lead to less respect for the legislation and I think that this is something which should be studied. Since random breath testing has proved to be such an effective measure, such knowledge could lead to the introduction of RBT also in the US.

BEHAVIORAL IMPAIRMANT OR TOLERANCE

The paper by Muriel Vogel-Sprott, “Low Blood Alcohol: Behavioral Impairment or Tolerance,” is an interesting paper presenting some very intriguing results. Is tolerance a cognitive phenomenon? Wouldn´t it be wonderful if we could only tell people that they are doing well while they are driving drunk and thereby make them as safe as when sober. I know I´m probably pushing the results a little too far but it would have been interesting to see a few words about the implications of the findings.

The report fails to inform us about the lenght of the tests – my guess is that we are dealing with rather short tests. Since alcohol is a sedative it might imply that in the long run, motivation to maintain sober performance may not be possible to sustain.

One question that comes to your mind is also whether the results indicate that inexperienced drinkers just have not learned what the norm is or whether they are just behaving according to the norm that says that inexperienced drinkers get more drunk.

Most DWI´s are probably highly motivated not to get caught, so is the solution to make sure that the level of police presence is high enough to make everyone aware of their presence? Or, if we can make them realize that there is a real danger of ending up in a crash, they will perform as if they were sober.

The paper does not mention whether a placebo design was employed or not. Such a design would probably illustrate the role of expectations in the best possible way.

It could be argued that there is no such thing as a real alcohol placebo. But there are others who claim that it works.

Well, a lot of intriguing thoughts BUT, a lot of people, maybe most, drink to get drunk and to free themselves of inhibitions – they are probably beyond the impairment reducing effects of motivation and expectations. They are willing to take risks or rather are not aware of them being risky.

I would like to see a study in which involves actual driving situations and test the motivational aspects.

Prevalence of Drivers and Drinkers with Low BACs

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INTRODUCTION

The purpose of this paper is to synthesize what is known about the prevalence of persons with low blood alcohol concentrations (BAC). This question is similar to, but also notably different from, that recently addressed in a special issue of *Alcohol Research & Health* on "moderate drinking." Whereas the purpose of that issue was to address the prevalence, distribution and known effects of moderate drinking on such things as heart disease, fetal development, and motor vehicle crashes, the goal of this workshop is to take a similar look at persons who have achieved an elevated, but low BAC. To begin I would like to mention just a few issues that, it seems to me, are important as we think about the policy implications of what we know and learn about the effects of low BACs. In particular, I believe it is important to strive for *conceptual clarity* and to be concerned with measurement precision.

Conceptual Clarity

Among the important conceptual issues is the distinction between 'low BAC' and 'moderate' or 'light' drinking, for they are not synonymous. Discussion and synthesis of research on the effects of moderate drinking is hampered by a number of definitional and measurement issues (Dufour, 1999). Moderate drinking is generally defined as consuming a certain number of drinks per unit of time. However, the meaning of any specific number of drinks is not at all clear since a standard 'drink' can vary both in serving size and alcohol content per unit volume.

By focusing on BAC in this workshop, and the various functional impairments associated with particular BAC levels, as opposed to 'amount of drinking,' we are able to avoid many of the measurement problems that complicate research on moderate drinking. To benefit from the clarity afforded by this precise measure, we must keep in mind that we are not necessarily talking about moderate (or light) drinking. Depending on how a person distributes drinks over time, a "moderate" drinker can reach higher BAC levels than a "heavy" drinker. Dawson et al. (1995) suggest identifying 4 to 14 standard drinks a week as moderate drinking and more than that as heavy drinking. A heavy drinker who consumes 2 drinks every week day, and 3 per day on weekends will rarely reach a BAC as high as a drinker who drinks 6 drinks on a Friday night and 6 on Saturday.

Following this point further, we also need to avoid the oversimplified notion that, by consuming a certain number of 'standard' drinks in a fixed period of time, an 'average' person will attain a particular BAC. Although such 'typical' estimates are useful for conveying some sense of what BAC means to the lay public, and can be useful as guidelines for individual behavior, they are too imprecise for scientific purposes. Addressing only part of this issue – the amount of alcohol in a ‘standard’ drink – Turner (1990) noted that consuming 3 ‘standard’ drinks (as operationalized in various respected research studies) could result in the consumption of anywhere from 12 to 24 grams (1 to 2 U.S. ounces) of alcohol. Beyond the uncertainty of the alcohol content in a ‘drink,’ we need to keep firmly in the mind the wide variation in BAC produced by the consumption of the same amount of ethanol, depending on the drinking rate as well as the sex, body weight, percent body fat and eating behavior of the drinker. Beyond that it is also important to remember the variation in effects associated with subjective factors like individual and situational expectations for alcohol effects.

The effects of particular BAC levels on the performance of various tasks is addressed by other presentations in this workshop. I will focus on the BACs actually attained by various groups, concentrating primarily on direct BAC measurement in several studies of motor vehicle drivers, to establish some understanding of how commonly the various effects of low BACs might be encountered on the roadways. We will also be able to shed some light on the claim that what many of us would consider to be heavy drinking could, hypothetically, produce a very low BAC due to drink spacing (as noted above).

Measurement and Reporting Precision

In the low BAC range (.01% - .05%), small increments probably make for substantial differences in behavioral effects. Accordingly, it is important that we use precise measurements when studying alcohol effects. To preserve the benefit of that precision, we must avoid ‘grouping’ errors that are produced when ranges of an independent variable, with different effects, are combined into a larger group.

The dynamic nature of BAC is also an important issue to keep in mind. In the BAC range we are considering in this workshop, we may well be at the lower thresholds for many effects. We will need to remember that unless drivers continue to drink at a rate that maintains or increases their BAC, these effects will be fleeting. Even though BAC declines relatively slowly, the range within which we are considering effects here (under .05%) is narrow, and meaningful declines within that range will occur in a short period of time after a person stops drinking.

ROADSIDE BAC SURVEYS

The roadside survey provides the best information available about the distribution of BACs among the driving public. In brief, a roadside survey involves interviews with drivers randomly sampled from roadways. The essence of a good survey is to provide parameter estimates using data that are representative of the general population of interest; to do this requires the use of probability sampling procedures. Accordingly, the roadways from which drivers are drawn are themselves typically selected to be representative of the broader community (sometimes a city, on other occasions an entire state, province, or nation).

Although specific details of roadside surveys vary somewhat, interviews are generally conducted on weekend nights – and sometimes week nights as well – between the hours of 10 p.m. and 3 a.m. Vehicles are directed off the roadway by a police officer, but direct contact with the driver is normally initiated by a research team member. Response rates in well-designed roadside surveys are extremely high, ranging from 94 - 96%, far exceeding those ever found in telephone and mailed questionnaire surveys. Among the small number of drivers who refuse to participate, reasons vary, but they tend to be unrelated to whether the individual has been drinking. The most common reason is typically being in a hurry and not wanting to take the time to do an interview. Frequently a person who does not wish to do the interview will provide a breath sample. Among those who do the interview, about 98% also provide a BAC measurement. Hence, there is little concern among roadside survey researchers that drinkers are disproportionately represented among non-cooperating respondents.

In order to minimize inconvenience to drivers, interviews are typically quite brief, consisting of a few questions about the evening's trip, drinking and a request for the driver (and sometimes passengers) to provide a breath sample. Interviews are always voluntary and confidential. Precautions are taken by the research team to ensure that no driver they discover to be impaired continues driving, but law enforcement intervention is not used to accomplish this.

Thus, the roadside survey avoids the problems of other sources of information about drivers' BAC. Unlike data from persons who have been in a crash, or who have been cited for DWI, RSS data accurately represent the driving population on the roadways (during the hours the survey is conducted). Unlike retrospective self-reports, roadside surveys involve a direct measurement that is not subject to intentional or unintentional distortion nor to the difficulties involved in estimating a BAC value from imprecise information about the number of drinks, their alcohol content, drink timing, etc.

Recent Roadside Surveys

Only one large-scale roadside survey (Dussault et al., 2000) has been conducted in North America during the past five years. Several surveys were completed during the first half of the last decade. In addition to the national roadside survey conducted in 1996 (Voas et al., 1998), surveys of smaller jurisdictions were conducted in Ohio (Meyers et al., 1993), Minnesota (Foss et al., 1993), North Carolina (Foss et al., 1997) and British Columbia (Beirness et al., 1997). Other community-specific surveys were conducted in California and South Carolina in conjunction with a large-scale community trials study (Holder et al., 2000). Here I will present information only from the National, British Columbia, Minnesota, North Carolina and Ohio surveys, for which detailed data on BAC distributions are available.

Populations studied: In North Carolina and British Columbia, the legal BAC limit was .08% at the time of the surveys. In Minnesota, Ohio, and the majority of sites in the National survey, the limit was .10%. The 1990 Minnesota and 1994 North Carolina surveys were conducted to provide statewide estimates of drinking-driving. The British Columbia survey was designed to represent only Vancouver and a smaller community, which together contain about 20% of the BC population. The Ohio survey represented two counties in northeastern Ohio. In the National, Minnesota and North Carolina surveys, communities were randomly selected. In all but the Ohio study, actual interview locations were selected in largely random fashion, though logistic and safety requirements preclude purely random sampling of sites for roadside interviews. Finally, in British Columbia, Minnesota and North Carolina, surveys were conducted on Wednesday, Thursday, Friday and Saturday nights. In Ohio and the National survey, data were collected only on weekend nights. Interviews typically began around 10 p.m., but in British Columbia data collection began at 9 p.m.

In all surveys, drivers were randomly selected from the traffic stream, but in British Columbia, North Carolina and at some locations in the National survey, interviews were conducted in conjunction with enforcement checkpoints. In practice, the BC surveys involved little active enforcement by officers and operations were much more characteristic of simple research surveys than were those in North Carolina, where numerous arrests were made. In those instances were enforcement actions were taken, that was incorporated into the study design and sampling plan; BACs were obtained from police officers for arrested drivers who had been sampled for the survey.

Prevalence of low BAC drivers: Figure 1 shows the proportion of drivers with a non-zero BAC for each of the five North American surveys of the 1990s. Figure 2 (a & b) presents a detailed breakdown of BAC distributions for alcohol positive drivers. Given the diverse locations, populations, times and BAC limits and other alcohol policies characteristic of these five jurisdictions, the similarities in the BAC distributions are striking. The proportion of drivers with any measurable alcohol ranges from 14% in North Carolina to 19% in Minnesota. These two states represent opposite ends of the spectrum in terms of the extent to which alcohol is a central element of the local culture. Nearly of adults in North Carolina are non-drinkers, whereas a substantial proportion of adults in Minnesota drink at least on occasion. (Note. The values for the national roadside survey shown in Figure 1 and below are based on analyses of the unweighted data obtained from Zador et al., 2000. Consequently, these differ somewhat from published reports from that study that use the weighted data.)

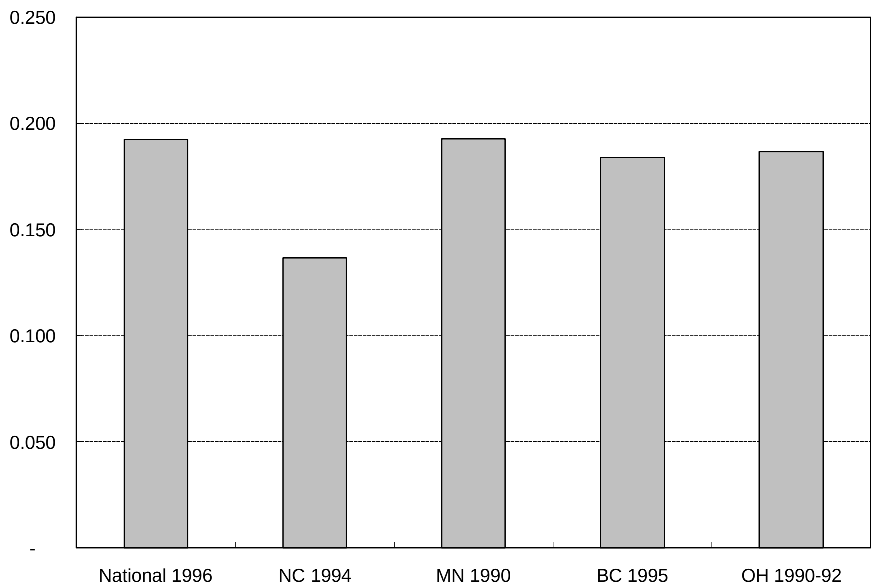

FIGURE 1 Drinking drivers in five roadside surveys.

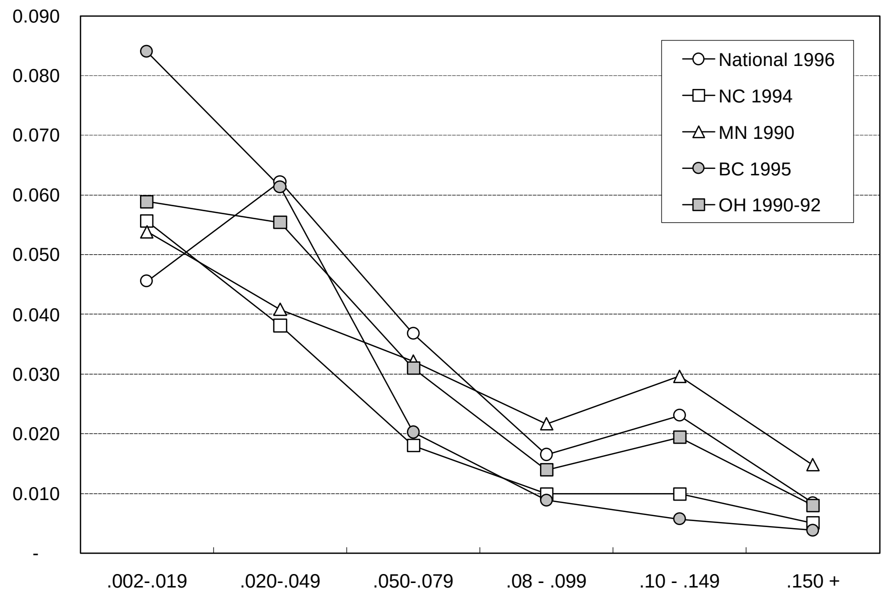

FIGURE 2a BAC distribution for all drivers.

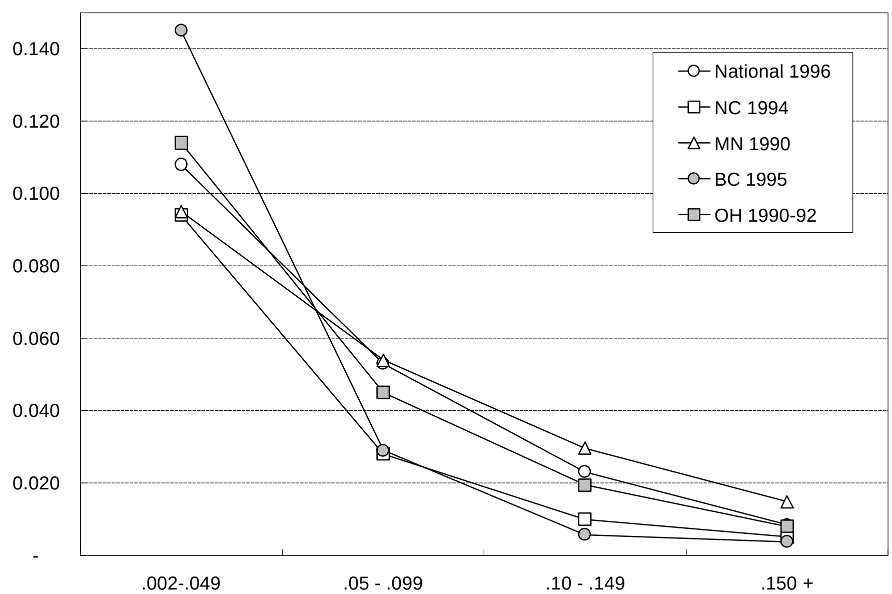

FIGURE 2b BAC distribution for alcohol-positive drivers.

The shapes of the BAC distributions among alcohol-positive drivers are strikingly similar as well (see Figures 2.a., 2.b). With the exception of Minnesota, the shapes parallel one another closely, especially in the distribution of BACs above .05%. All five surveys found substantially more drivers with low BACs, with a steep decline in the proportions above .05%. There is a bump in all the surveys (except BC) at .10% - .149%, but this is an artifact of the way the BAC range is typically grouped, to include splits at the two common BAC limits of .08% and .10%. The lower proportion of very low BAC drivers in the National survey is an artifact of reporting. For those data, BACs of .002% through .004% were rounded to zero. In the other surveys, BACs of .002%

through .004% are included in the lowest positive BAC category. Figure 2.b. represents the shape of the BAC distributions more accurately by presenting equal size BAC ranges.

The focus of this workshop is on the effects of low BAC, defined as BACs ranging up to .05%. Figures 3.a. and 3.b. present information about the prevalence of low BAC drivers in the five roadside surveys. Figure 3.a. gives the proportion of drivers found to have low BACs (excluding drivers with both higher and zero BACs). These give the best available indication of the proportion of all drivers during peak drinking hours (after 10 p.m. on weekends) who may experience the effects being considered in this workshop.

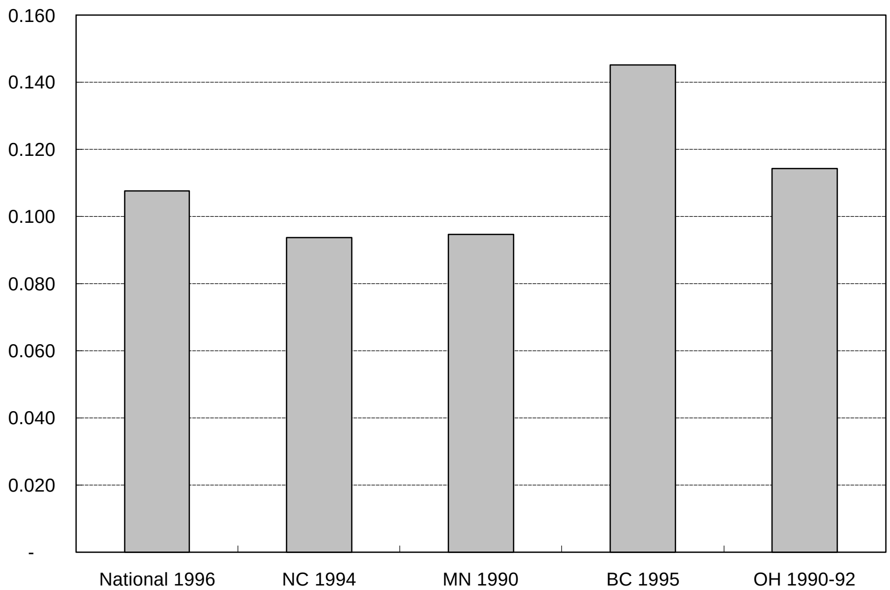

FIGURE 3a   Proportion of drivers with low BAC.

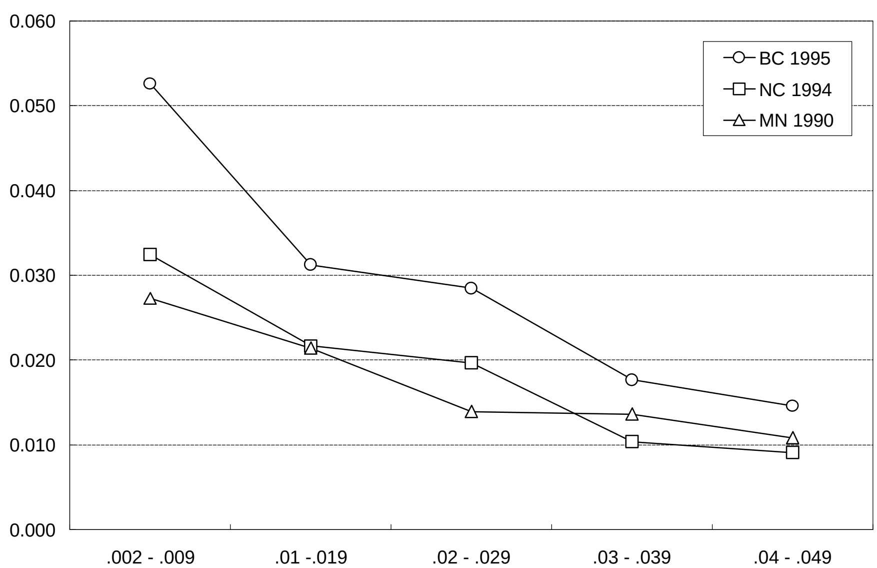

FIGURE 3b   Detailed breakdown of BAC distributions for low BAC drivers

Figure 3.b. presents a breakdown of specific BAC values among the low BAC groups for three of the roadside surveys. This highlights the risk of grouping data when the underlying distribution does not at least approximate a normal distribution. The BAC distribution found in each of the roadside surveys is monotonically decreasing. The implication, for our purposes here, is that when we consider the effects of low BACs, it is important to be precise – that is, to avoid grouping errors wherein aggregating across a range of values obscures meaningful distributional differences within that range. Thus, for example, we must be careful not to assume that findings about the impairing effects of a BAC of .04% characterize 10 - 11% of the nighttime driving population in North America (i.e., all drivers with positive BACs up to .049%). Instead, it will be more prudent to assume that these impairments represent only about 1% - 1.5% of drivers (in addition, of course, to those with BACs above .05%) driving late on weekend nights.

Figure 4 shows the proportion of drivers with low BACs by day of week for two surveys where data were collected on weeknights as well as weekends. In both BC and Minnesota, the proportion of drivers with low BACs is greater on weekends, though not dramatically so. This is important to keep in mind. Because the majority of nighttime driving occurs during the week, attributing rates of drinking driving based on studies conducted only on the highest drinking nights (Friday and Saturday) will overestimate the prevalence of alcohol-involved driving. Although the national roadside survey was carefully designed and conducted to provide an estimate of drinking-driving for the entire U.S., that information should not casually be generalized to the nighttime driving population as a whole, but rather only to weekend nights.

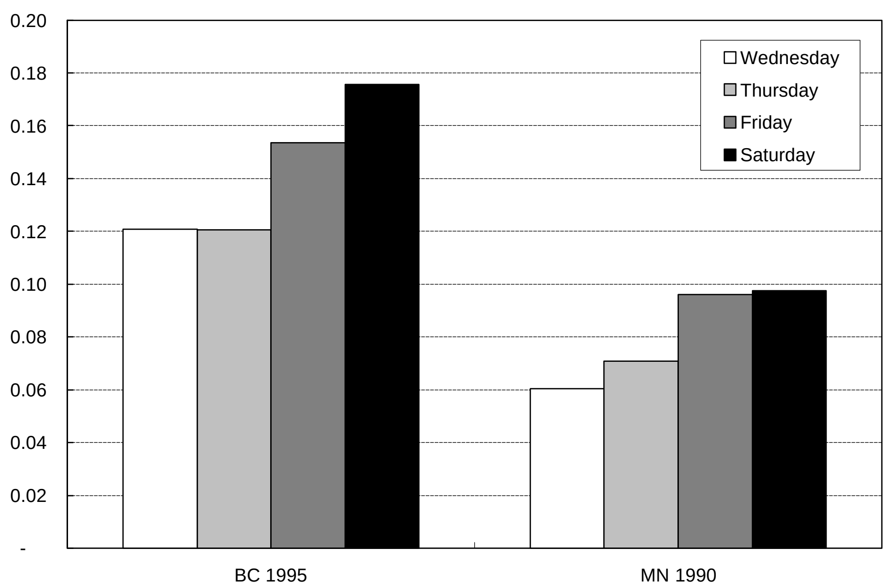

FIGURE 4   Low BAC drivers by day of week

Roadside surveys are conducted primarily on weekend nights for logistic reasons; that is when drinking-driving has long been thought to be more common. Studies that have examined other nights of the week bear out that assumption, though they indicate that differences between weekend nights and weeknights are perhaps not so great as is typically believed. Neither high nor moderate BACs among the general nighttime driving population are so different on weekends compared to weeknights, as the differential in alcohol-involved crashes on weekends vs.

weeknights would lead us to suspect. This raises the question of what we know about drinking-driving outside the late night hours typically covered by roadside surveys.

There is some indication that at least some women may be more likely to drive after drinking in the afternoon, giving rise to the unsettling prospect that focusing only on the high risk hours that characterize typical male drinking patterns may have led us to miss an important phenomenon. Helping to alleviate that concern somewhat, Farris (1976) obtained BAC data from drivers at all hours of the day and found that drinking-driving is, in fact, quite uncommon during the morning, afternoon and evening hours. These are quite old data, however.

CHARACTERISTICS OF LOW BAC DRIVERS

Because roadside survey interviews are typically brief, only a small amount of information is available about these drivers for whom a BAC is known. Figure 5 provides a comparison of the proportion of all males and females whose BAC was in the low, but positive range. Males are consistently overrepresented among the low BAC drivers. Whereas males make up just over two-thirds of the driving population sampled in these surveys (ranging from 65% in North Carolina to 69% in BC and Ohio), they represent about three-quarters of low BAC drivers (ranging from 78% in BC to 71% in Minnesota).

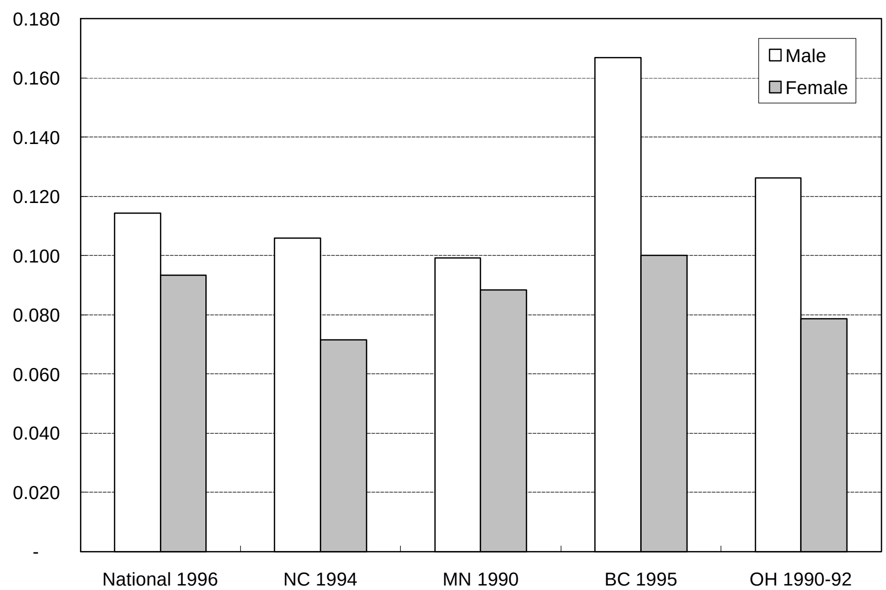

FIGURE 5 Low BAC drivers by sex

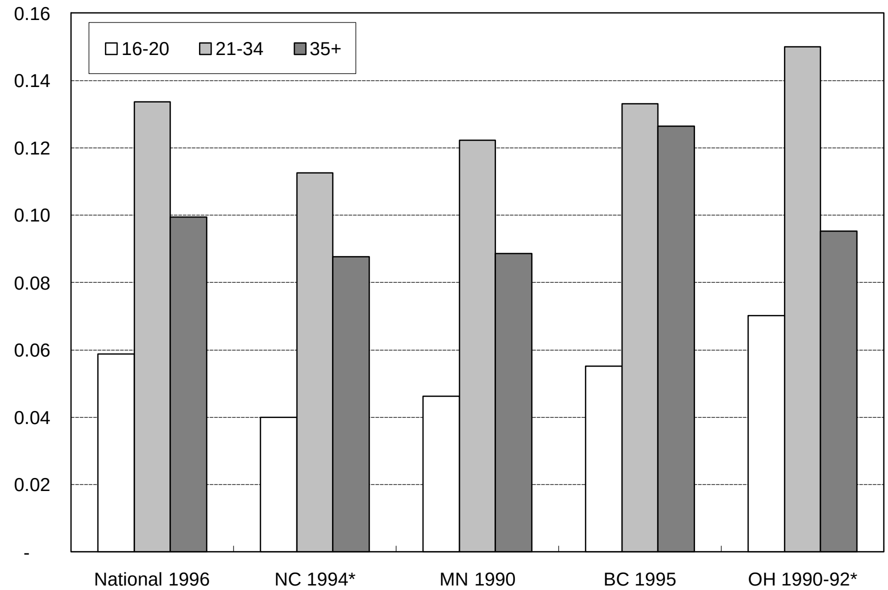

FIGURE 6 Low BAC drivers by age (Note. In NC and Ohio the young group is 18 - 20.)

Figure 6 shows the proportion of three age groups with low BACs. Among the 21 - 34 age group 11% - 15% of all drivers have low BACs. Drivers 35 and older are only somewhat less likely to have low BACs. The proportion of this age group found to be driving with a low BAC is consistently between 9% and 10% in the U.S. surveys, but is somewhat higher (13%) in the B.C. survey. Among drivers under the legal drinking age (in the U.S.), the proportion with a low BAC is consistently about half that of 21-34 drivers. Although the legal drinking age in British Columbia is 19, the roadside survey data show no evidence of greater drinking to low BACs among the young age group than in the other jurisdictions.

OTHER "CHARACTERISTICS" OF LOW BAC DRIVERS

In addition to simple descriptive data about drivers obtained from roadside surveys, we have learned a few other things as well.

Seatbelt use: It is well documented that drinking drivers are likely to engage in a range of other risky behaviors as well, including a tendency not to wear a seat belt. This association of seatbelt (non)use and drinking was found as well among drivers interviewed in the Minnesota survey, (Foss, Beirness & Sprattler, 1994). However, there was a threshold effect at about .10%. Belt use was relatively stable across BACs from .00% to .09%, dropping off sharply among drivers with higher BACs. This provides some indication that low BAC drivers may be systematically different from higher BAC drivers, in ways other than drinking.

BAC estimation ability: Beirness, Foss & Voas (1993) examined drivers' ability to estimate their BAC. Drivers interviewed in the Minnesota survey who reported drinking were shown a delineated scale of possible BAC values, ranging from .00% to .24%, with the legal limit clearly marked at .10%. They were asked to indicate what they thought their BAC was at the time using the visual scale. Although there was a moderate association between actual BAC and estimated BAC (r = .42), there was a strong tendency for drivers to underestimate their actual BAC. It is noteworthy, however, that persons with low BACs (.02% - .049%) were generally fairly good. Although only about 30% were within .01% of their actual BAC, underestimates and overestimates were equally likely. On the other hand, among persons whose BAC was higher – but still under the legal limit – 70% underestimated their BAC and fewer than 10% overestimated. Even recognizing that there is more room for error at higher BACs, the strong tendency to underestimate indicates that these errors are not random.

One of the noteworthy findings from this analysis of BAC estimation abilities or tendencies, was the very strong tendency for young drivers (16 - 20) to underestimate their BAC. Although the mean (and median) BACs among the young drivers who had been drinking were nearly identical to those of older drinking drivers, 70% of underage drinkers underestimated their BAC, whereas only about 42% of older drivers underestimated.

Likelihood of detection: A study by Wells et al., (1997), using data from the 1994 North Carolina roadside survey, provides a hint about difficulties of enforcing BAC limits lower than .10%. Since the NC roadside survey was conducted in conjunction with law enforcement sobriety checkpoints, there was an opportunity to determine how often legally impaired drivers were missed by officers. At every data collection session, all drivers were subject to law enforcement screening. Drivers were sampled for participation in the survey prior to entering the enforcement checkpoint. If a sampled driver was detained or arrested by an officer, the BAC was provided to researchers. If the driver was passed through the checkpoint, he was interviewed by a member of the research team. It should be noted that NC law enforcement officers have a well-deserved reputation for being aggressive in their efforts to detect drinking drivers and that was evident at the survey sites. Among sampled drivers whose BAC was above the legal limit of .08%, 62% were missed – that is they were neither arrested nor detained for further investigation – even though they had been interviewed by an officer at the checkpoint. Among persons with a BAC from .05% - .079%, who might have exhibited enough evidence of drinking to warrant further investigation, 87% were not detained. This illustrates how difficult it is to detect persons with BACs in the range where obvious signs of impairment are uncommon.

Other data obtained from roadside surveys also point to the difficulty of detecting low BAC drivers for enforcement purposes. Perrine et al. (1992) reported on the ability of the Standard Field Sobriety Tests (one-leg stand, walk-and-turn, horizontal gaze nystagmus) to discriminate between drivers at various BAC levels. All drivers with a non-zero BAC, as well as a sample of zero BAC drivers, were administered the three SFSTs according to standard protocol, in conditions approximating those that are typical for officers on DWI patrol or at checkpoints: outdoors, in relative darkness, in parking lots adjacent to roadways. Three different groups conducted these tests: trained interviewers, police officers and SFST experts who teach SFST procedures to police officers. Using standard scoring procedures, failure rates on the walk-and-turn test were largely unrelated to BAC, even when conducted by the SFST experts. For the one-leg-stand, failure was generally unrelated to BACs below .15%. In contrast, failure on the HGN test showed a direct and clear linear association with BAC. Nonetheless, failure rates on the gaze nystagmus test were low for persons with low BACs.

We might hope that where human judgmental abilities are not particularly good at detecting low BACs, a technological device such as a passive alcohol sensor would prove more useful. There are some data from studies of passive sensors in field settings that help to address this issue. In the Minnesota survey, both a passive sensor reading and a measurement with a portable breath test device were obtained for nearly 1,200 drivers (Foss, Voas & Beirness, 1993). Although passive sensors were not particularly good at determining whether drivers were above or below higher BAC thresholds (such as .10%), due to relatively high rates of false negatives, they were quite good at distinguishing between persons with BACs of .02% or above and those with essentially zero BACs. Stated differently, if a passive sensor is used merely to detect alcohol – thereby prompting further investigation – it appears to be quite effective, even at lower BAC levels (cf., Ferguson, Wells & Lund, 1995; Kiger, Lestina & Lund, 1993). However, Leaf & Preusser (1996) identify a number of logistic difficulties identified by police officers working with passive sensors to help enforce low BAC limits for youth.

HYPOTHETICAL AND REAL BAC AS A FUNCTION OF NUMBER OF DRINKS

Variation in BAC for Similar Consumption

It is possible to reach a wide range of BAC levels with the same number of "drinks," depending on drink size, alcohol content of the drink, drinking rate, body size and composition, sex of the drinker, and coincident eating behavior. Although consuming 5 'standard' drinks in a one-hour period is sufficient to produce a BAC of about .08% for a 170 pound male, that is a highly atypical drinking pattern. Although it is not uncommon for some drinkers to consume 5 or more drinks on an occasion, their drinking is normally spread out over a longer period of time (Gallup, 2000). Hingson et al. (1999) took an important step in broadening our perspective on the BAC that might be expected as a result of drinking. By illustrating the effects of consuming 'standard' drinks by 'typical' males and females over two time periods, they show that 'moderate' consumption (in this case two drinks) can result in BACs ranging from .01% to .05%.

In recent years, a basic understanding of the metabolism of alcohol has been used extensively by college students to deny the importance, or relevance, of widely reported information about the prevalence of student "binge" drinking (Wechsler et al., 1998; 2000). Although it is possible to drink five or six drinks in an evening and remain at a relatively low BAC, a particularly pertinent question is: "Does that actually happen?" or perhaps "How commonly does that occur?" Data we have collected from a large sample of university students help to address this issue.

In the fall of 1997 and again in 1999 we used an adaptation of roadside survey procedures to interview and obtain breath measurements from a representative sample of university students on one campus as they returned home in the evening. We measured BACs of nearly 4,000 respondents in two separate probability sample surveys of college students as they returned home between 10 p.m. and 3 a.m. (see Foss, Marchetti & Holladay, 2001, for a more detailed description of the method).

One analysis of these data produced an interesting result. Although it is tangential to the topic of the present workshop, it does go to the issue of the relationship between BAC levels that might be reached, assuming various patterns of drinking a given number of drinks, and what one population of drinkers actually does. A commonly reported measure of student drinking is the percent who admit to having consumed 5 or more drinks (4 for females) on an occasion at some point during the past two weeks. Looking at the measured BAC of those persons who reported having that many drinks on the evening they were interviewed, there is some evidence that this "binge" measure may indeed lead to an exaggerated notion of student impairment. Fifty-two percent of those who reported this amount of drinking had BACs in a range (< .10%) that, while involving various kinds of impairment, certainly don't reflect the "drunkenness" that the term "binge" connotes for many. At the same time these results clearly indicate that, although it is possible to drink 4 or 5 drinks and maintain a relatively low BAC, students don't typically do so. Figure 7 shows the BAC distribution for 270 students who had consumed enough drinks to be labeled "bingers" on the evening they were interviewed.

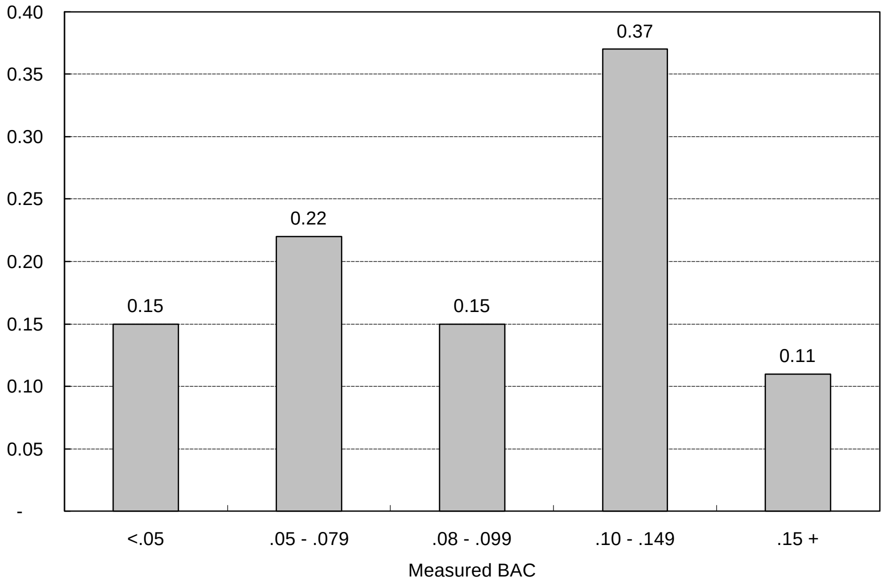

FIGURE 7   BACs obtained by "binge" drinkers

Figure 8 shows the mean measured BACs for all those who said they had been drinking, as a function of the number of drinks they reported consuming during the evening. This gives a hint of the kind of BACs we might expect, based on self-reported number of drinks on an occasion. The various intentional and unintentional distortions that may be involved in reporting number of drinks consumed (other than memory, since the present data involve remembering only a few hours, not days, weeks, or longer) are included, as is the variation in drink size, alcohol content, eating behavior and the like. A curious issue here is the dip in average BAC of persons reporting 7 drinks below that for those reporting 5 or 6. At present we have no explanation for this aberration. This could be evidence that those reporting fewer drinks, especially 5 or 6 may be hedging or rounding their reports downward.

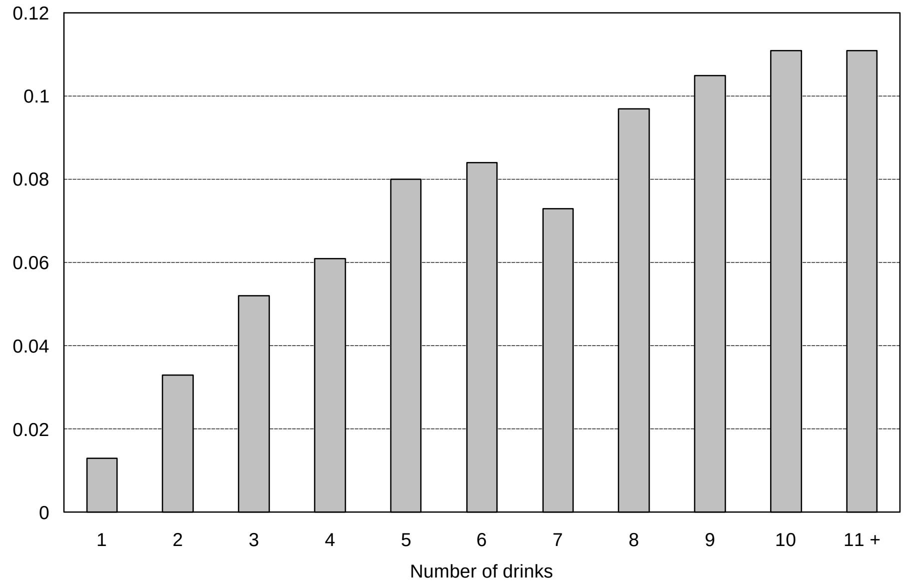

FIGURE 8 BAC in relation to reported number of drinks

SELF REPORTS OF DRINKING-DRIVING

In view of the variety of factors that are critical in the BAC that a person will reach when drinking, it is difficult to get a valid indication of BACs among individuals in general or for drinking drivers in particular using standard self-report measures. Many self-report studies use questionable measures to examine driving after drinking. For example, Liu et al. (1997) estimated the number of "alcohol impaired" trips by drivers in the U.S. during 1993 based on replies to a single, nebulous question: "How many times in the past month have you driven after you've had perhaps too much to drink?" One central finding reported in that study – that 18-20 year-old males are nearly as likely to drive after drinking as 21-34 year-old males – differs dramatically from roadside survey findings. Whereas Liu et al. estimate 1.62 "impaired driving" episodes per person for underage males, compared to 1.74 per person for 21-34 year-old males, roadside survey data repeatedly indicate that drinking-driving is more than twice as likely among the older age group than among 18-20 year-olds.

Until fairly recently, weak measurement has been common in surveys that ask about drinking-driving. That has begun to change, and one national survey is far more careful in assessing "impaired driving." The biennial *National Survey of Drinking and Driving Attitudes and Behaviors* sponsored by the National Highway Traffic Safety Administration obtain sufficiently detailed information to be able to provide a reasonable BAC estimate for drivers. Several questions focus on a specific (the most recent) occasion when respondents drove after drinking any alcohol within the previous two hours. Results of the most recent (1999) survey are of particular interest for us in this workshop. They indicate that "the vast majority of drinking-driving trips are made by persons with estimated BAC levels below .05%" (Gallup, 2000). Specifically, 82% of all drinking-driving trips occurred with estimated BACs less than .05%, and 87% of the "most recent" drinking-driving trips are estimated to have occurred when the driver's BAC was below .05%. Additional notable findings from the 1999 survey are that persons who report having driven after drinking drink an average of 2.8 drinks per drinking occasion, somewhat more than the 2.1 per occasion for those who report not driving after drinking. On their most recent drinking-driving episode, respondents report drinking 2.7 drinks over an average of 3.7 hours, stopping about 45 minutes before driving.

These results differ fairly clearly from findings of the various roadside surveys, wherein the non-zero BAC distributions are not so heavily concentrated in the lower BAC range. To illustrate, the Ohio roadside survey obtained information about whether a driver had been drinking within the two hours prior to the interview, paralleling the question in the NHTSA telephone survey.

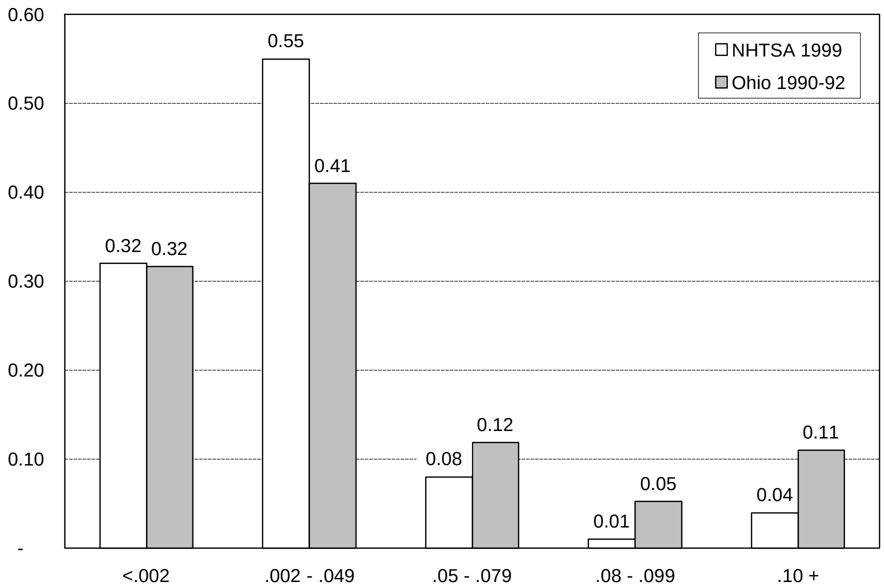

FIGURE 9 Comparison of self-report and measured BACs

Figure 9 shows a comparison of the estimated and measured BAC distributions among drivers who report drinking within two hours before driving. Clearly these two surveys differ in a number of ways that make them not directly comparable. The telephone survey was more recent (although BAC estimates were even lower in the 1995 and 1997 surveys), dealt with trips that could have occurred at any time of day or week, and was for a national population (although results of the Ohio roadside survey parallel those of the national roadside survey closely). Keeping these differences in mind, there is a clear pattern of differences that is consistent with underreporting of drinking, or overreporting of drinking duration, for persons who consumed more than a small amount. For our purposes in the present workshop, it may be that results from that national self-report survey overestimate the amount of driving at low BACs (at the cost of underestimating the amount of higher BAC driving). Alternatively, the greater proportion of low BAC trips may represent driving at times of day, and days of the week, that are not captured in roadside surveys. In either case, it is clear that most drinking-driving trips involve a driver has a relatively low BAC.

CONCLUSIONS

In brief, we have good relatively recent evidence about the prevalence of driving with a low but positive BAC in the U.S. indicating that on weekend nights from 10 p.m. to 3 a.m. about 10% of drivers have a positive but low BAC (< .05%). Moreover, among those about 2% are between .03% - .049%, about 4% range from .01% - .029% and another 3% are marginally positive, ranging from .002 - .009%. The demographic make-up of low BAC drivers is similar to that of all drinking drivers: males are more likely than females to have low BACs and drivers ages 21-34 are more likely than other ages, especially teen drivers, to have low BACs. It appears that driving with a low BAC is somewhat more common on weekend nights than during the week.

The remainder of what we "know" about low BAC drivers from field studies is limited. Single studies suggest that low BAC drivers are as likely to wear seatbelts as non-drinking drivers and are better at estimating their BACs than higher BAC drivers. A few studies have looked at DWI enforcement issues, including field experiments with passive alcohol sensors and field sobriety tests, as well as the actual success of officers in identifying drivers at higher BACs than those we are concerned with here. These generally suggest that effectively enforcing laws that prescribe BAC limits lower than .08% will be extremely difficult. Passive sensors clearly can be useful, but there are substantial obstacles to implementing their routine use.

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Epidemiology: Crashes At Low BACs

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INTRODUCTION

The focus of this workshop of the Transportation Research Board (TRB) Committee on Alcohol, Other Drugs, and Transportation is the laboratory and epidemiological evidence of the effects on driving and highway safety of impairment at low blood alcohol concentration (BAC) levels, and the implications of these findings for public policy and future research. This presentation will focus on the epidemiology of traffic crashes at low BAC levels, including the incidence of crashes at low BACs, an examination of the characteristics of crash participants, and an estimation of the extent to which alcohol was a causative factor in these crashes. This presentation will review existing research on the topic, identify gaps and flaws in current knowledge, and identify policy implications and recommendations for change and/or further research.

General Background

In discussing the epidemiology of traffic crashes at low BAC levels, let us begin with an obvious conclusion supported by the preponderance of research evidence in this field; namely that the higher the BAC level of a driver, the greater the probability of a fatal crash. By inference and evidence, one can also conclude that the probability of a fatal crash, or any crash for that matter, decreases in tandem with declines in BAC level, although the nature of that relationship may or may not be linear.

Perhaps the most widely recognized study in this field is the “Grand Rapids” study (Borkenstein et al, 1964), a case-control study which estimates the contribution of alcohol to crash involvement by comparing the BAC levels of crash involved drivers with a non-crash-involved comparison group. In case control studies, BAC data on crash-involved drivers are typically collected from police accident reports, while the comparison group is identified through roadside breath test surveys of drivers at similar times and locations. The first such case-control study was done by Holcomb in 1938, and the study methodology has been replicated a number of times since. Figure 1 (Hurst, 1985) combines data from several of these studies, including the Grand Rapids study, and the curves describe the relationship between BAC level and crash involvement (based on the ratios derived from the BAC levels of crash-involved and comparison subjects). While the methodology is imperfect (the groups are not randomly assigned, and may be different on relevant factors), and the studies varied in the use of fatal and injury crashes versus total crashes, the resulting curves are still remarkably similar. These data appear to show a relatively modest increase in crash involvement with rising BAC, at least until about 0.06% to 0.08%, with a sharp increase in crash risk with BACs above that level. The curves shown in Figure 1 would seem to reflect a relatively modest increase in crash risk for BAC levels below 0.08%. In fact, based on the Grand Rapids data, it would appear that the crash risk for drivers at very low BACs (0.02%) is actually lower than the risk of the comparison drivers! This well known anomoly, called the "Grand Rapids Dip," is actually a reflection of the imperfection of the study methodology and the lack of perfect comparibility between the crash and comparison subjects. Hurst has demonstrated that crash risk at low BAC levels is moderated significantly by the tolerance level of the driver.

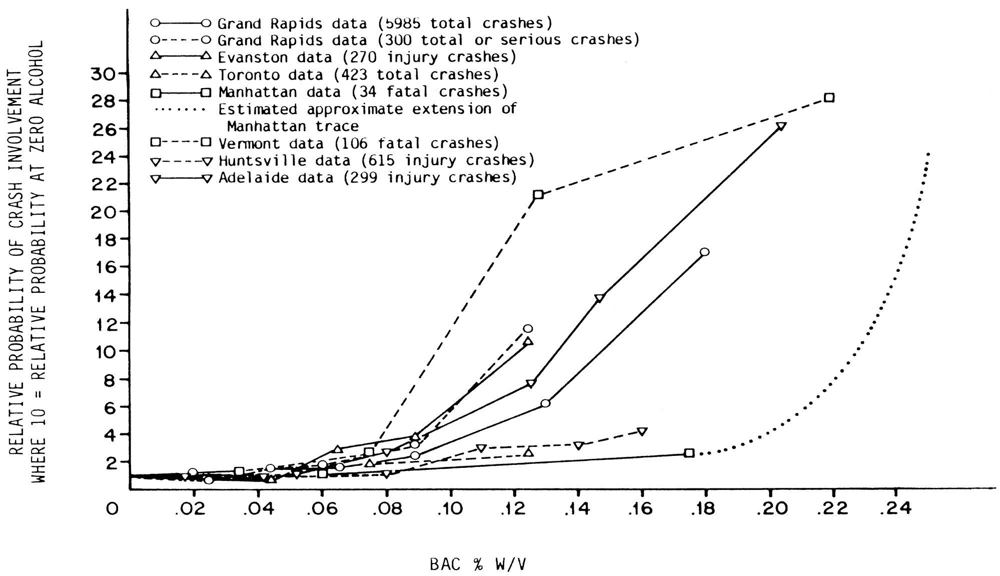

FIGURE 1 Relative probability of crash involvement as a function of BAC.

For example, drivers who are regular drinkers and have developed a tolerance to alcohol and learned to function under its effects are much less likely to be crash involved at lower BAC levels. Because drivers who are intolerant to or inexperienced with alcohol are more likely to be crash involved at low BAC levels, they are therefore relatively more likely to be part of the crash group than the comparison group. This inequitibility between the crash and comparison groups on experience with alcohol confounds the odds ratios, and results in the comparison group, with the more experienced drinkers, showing a lower crash risk at 0.02% BAC than does the crash group. While this artifact is graphically evident in Figure 1 at 0.02%, the inequitibility between groups is likely to exist at all BAC levels. One of the effects of this bias is a general and systematic underestimation of crash risk at low BAC levels. When this bias is controlled for, the apparent curvilinear relationships shown in Figure 1 tend to flatten, and the "threshold effect" apparent at 0.08% to 0.10% tends to disappear. For drivers who are daily drinkers, for example, the relationship between BAC level and crash risk is almost linear.

The implications of this linear relationship are significant. While the original curvilinear plots of BAC level and crash risk would imply that the effects of alcohol are somewhat suppressed at lower BAC levels, the adjustment for drinking experience produces plots which reflect a fairly steady increase in crash risk at all BAC levels. The conclusions one might reach based on these two graphs are strikingly different and heuristic: the "threshold effect" of the curvilinear plot might lead one to conclude that the increases in crash risk associated with alcohol consumption only "kick in" above a certain BAC level, hence the consumption of smaller amounts of alcohol is "relatively" less risky. The plots adjusting for drinking experience might invoke a different interpretation and conclusion: namely, that any amount of alcohol leads to increased crash risk.

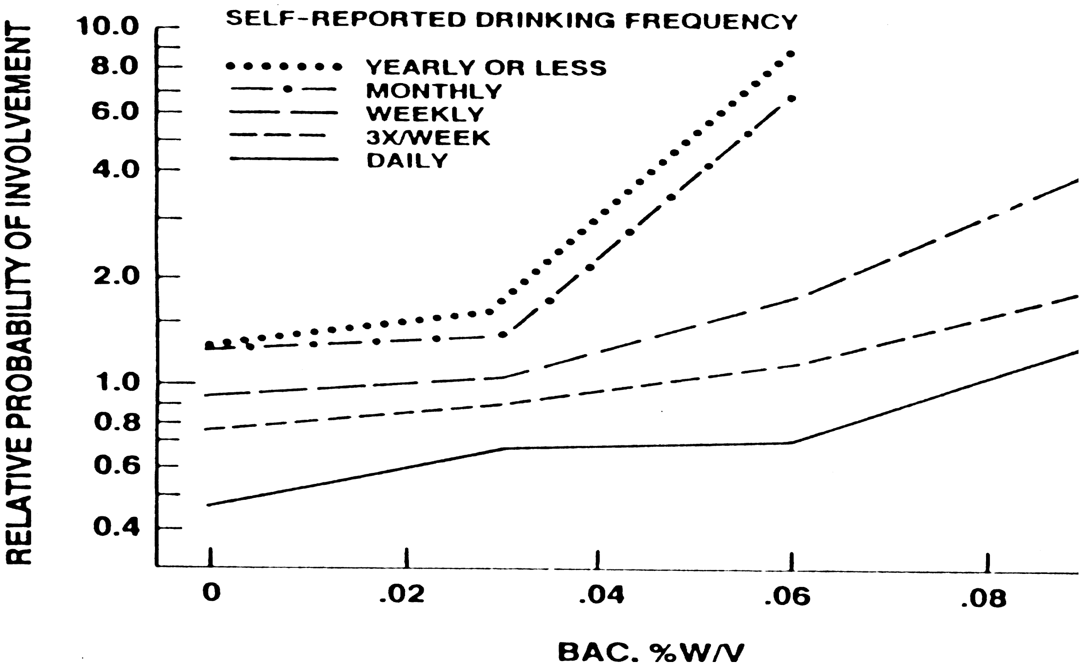

FIGURE 2 Relative probability of crash involvement by self-reporting drinking frequency (Hurst, 1973). Reprinted with permission from the Journal of Safety Research, a joint publication with the National Safety Council and Pergamon Press, Ltd.).

Another implication of the relationship between drinking experience and crash risk at any BAC level is that younger drivers, who would naturally tend to be less experienced at drinking (and driving) than older drivers, would tend to be overinvolved at lower BAC levels. In looking at the types of drivers involved in alcohol-related crashes, Borkenstein et al, in the Grand Rapids study, concluded that "the young, the very old, the inexperienced, and the uneducated" were overrepresented, particularly in low BAC crashes" (Borkenstein et al, 1964, pp. 6-7).

Incidence of Crashes at Low BAC Levels

Before delving further into the types of drivers who might be overinvolved in crashes at low BAC levels, let's review the evidence on the incidence of crashes at low BAC levels.

TABLE 1 Estimated Incidence of Alcohol Involvement in Crashes, by BAC Level

Crash Type	0% BAC	< 0.10% BAC	> 0.10% BAC
Fatal	.62	.08	.30
Injury	.80	.05	.15
PDO	.96	.01	.03

According to the most recent (1999) United States fatal crash data from the Fatal Accident Reporting System (FARS) at the National Highway Traffic Safety Administration

(NHTSA), in 1999, alcohol was estimated to be involved in 38% of all fatal crashes (NHTSA Traffic Safety Facts, Alcohol, 1999), with 30% of fatal crashes involving BAC levels of 0.10% or higher, and 8% involving BAC levels of less than 0.10%. The involvement of alcohol in injury-only and property-damage-only (PDO) accidents is not as well studied or understood as with fatal crashes, primarily because of the lack of BAC testing in nonfatal crashes. Donelson (1988), however, estimated the magnitude of the alcohol crash problem to be 50% of fatal accidents, 25 to 30% of injury crashes, and 5 to 10% of PDO crashes (including only drivers with BAC levels of 0.10% or above). These estimates appear fairly high, however, not only relative to current reduced levels of alcohol crash involvement, but when compared with the findings of the Grand Rapids study, one of the few case-control studies to look at all crashes (not only fatals). That study found only 5% of all noninjury crash involved drivers to have BAC levels in excess of 0.10% (Donelson, 1988, p. 25). The proportion of injury and PDO accidents associated with low BAC levels is unknown, but if one assumes the same proportion of < 0.10% BAC involvement as with 1999 fatal crashes (.08/.38 = .21), then, using Donelson's estimates as the base, the proportion of injury crashes associated with BAC levels less than 0.10% would be approximately 5 to 6%, and the proportion of PDO crashes associated with BAC levels less than 0.10% would be approximately 1 to 2%. Given that nonfatal accidents comprise approximately 99% of all crashes, the estimated proportion of all crashes involving BAC levels below 0.10% would be approximately 1 to 3%. The incidence of crashes at very low BAC levels (e.g., 0.02%) would be even less than the estimated 1 to 3%, of course. If low BAC levels were associated with even 1% of crashes in the US, however, that numerical total would still be over 60,000 crashes annually.

TABLE 2 Alcohol Involvement for Drivers in Fatal Crashes, 1989 and 1999

Drivers Involved in Fatal Crashes	1989 Number of drivers	1989 Percentage with BAC 0.10 g/dl or greater*	1999 Number of drivers	1999 Percentage with BAC 0.10 g/dl or greater*	Change in percentage, 1989-1999
Total Drivers					
Total*	60,435	24	56,352	17	-29%
Drivers by Age Group (years)					
16-20	9,442	20	7,973	14	-30%
21-24	7,723	35	5,620	27	-23%
25-34	15,928	32	11,734	24	-25%
35-44	10,106	25	11,023	21	-16%
45-64	10,240	17	12,292	13	-24%
Over 64	5,431	7	6,559	5	-29%
Drivers by Sex					
Male	45,448	27	40,900	20	-26%
Female	14,054	14	14,792	10	-29%
Drivers by Vehicle Type					
Passenger cars	35,204	24	27,806	17	-29%
Light trucks	15,579	28	19,801	20	-29%
Large trucks	4,903	3	4,847	1	-67%
Motorcycles	3,182	40	2,515	28	-30%

Source: NHTSA Traffic Safety Facts, Alcohol, 1999

*Numbers shown for groups of drivers do not add to the total number of drivers due to unknown or other data not included

Characteristics of Alcohol-Involved Crash Drivers

Looking at the age distribution of >0.10% BAC drivers in fatal crashes in the most recent FARS 1999 data, one can see the highest involvement among drivers just above legal drinking age (with 27% of such drivers aged 21-24 >0.10%) with declining involvement among age groups in either direction of the age spectrum (24% for ages 25-34, 21% for ages 35-44, 13% for ages 45-64 and only 5% of fatal crash drivers over age 64, with 14% of drivers aged 16-20 being above 0.10% BAC).

While 14% of fatal crash drivers aged 16-20 were above 0.10% BAC, it is interesting to note the steep decline in such drivers since 1986, when 21% of fatal crash drivers aged 16-19 were tested at 0.10% BAC or higher (Fell, 1987). It's also interesting to note in Fell's study that the proportion of alcohol-involved fatal crash drivers with BAC levels from 0.01% to 0.09% is directly correlated with age, with the youngest drivers (aged 16-19) having the highest proportion (13%, compared to 8% or less of drivers aged 25 or older) of such alcohol-involved, but below the legal limit, fatal crash involved drivers. These data support the conclusion that younger drivers are at higher risk at lower levels of alcohol, which makes sense given the relative inexperience of younger drivers at both drinking and driving. Simpson (1985), in fact, has shown that underage drivers have the highest fatal crash risk at every BAC level (Figure 3).

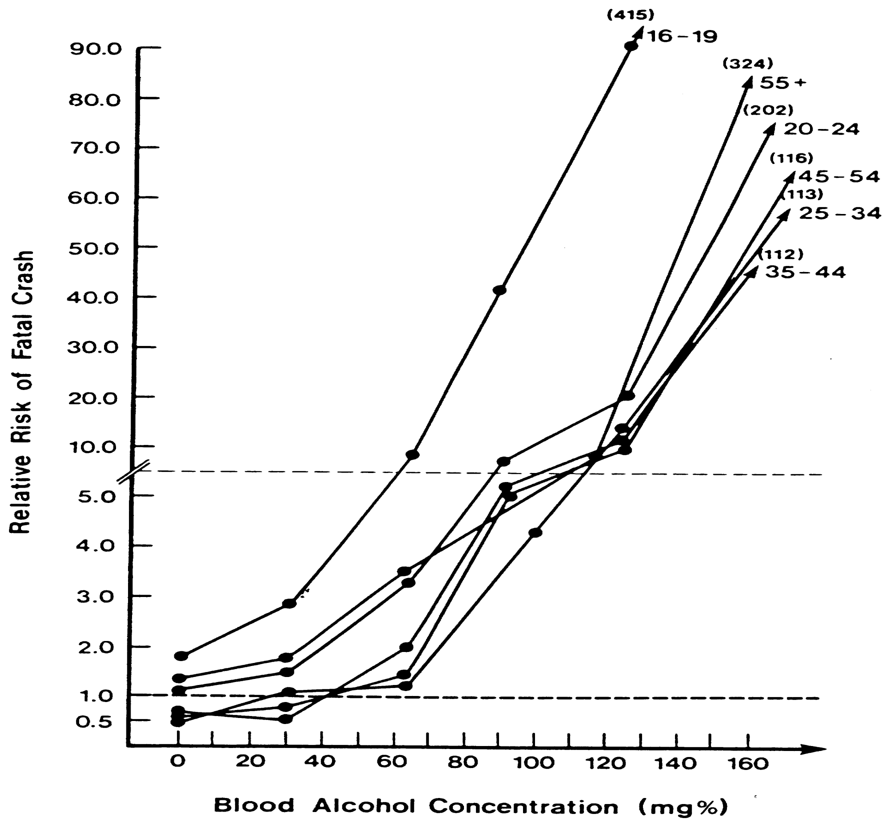

FIGURE 3 Relative risk of fatal crash as a function of BAC and age.

Underage (<age 21) drivers accounted for 6.8% of all licensed drivers in the United States in 1999, but were involved in 18% of all crashes and 15% of all fatal crashes, rates two to almost three times their population parity. 14% of underage drivers killed in crashes had BAC levels in excess of 0.10%. Fell (1987) showed that 18-20 year old drivers had the highest proportion of >0.10% BAC drivers on a per-mile-driven basis, while 21-24 year old drivers had the highest rates per licensed driver and per capita, and the 1999 FARS data show substantially the same pattern. Clearly, drivers under age 25 are overinvolved in alcohol-related crashes.

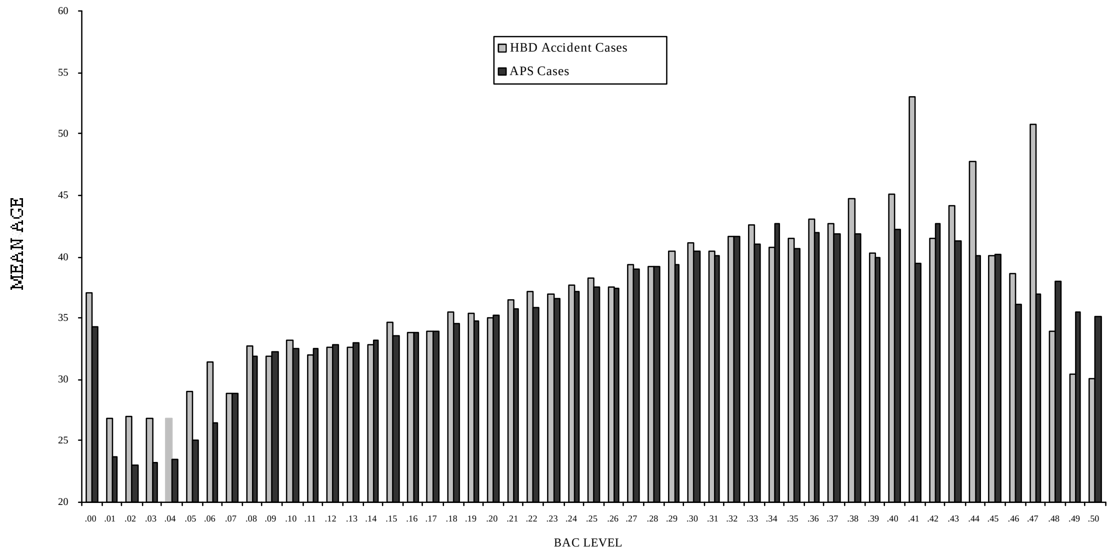

FIGURE 4 Average (mean) age of DUI arrest (APS) and alcohol-involved crash (HBD) cases by BAC level.

Based on current California data, younger drivers arrested for DUI and/or involved in alcohol-related crashes are also overrepresented at the lower end of the BAC spectrum. Figure 4 shows a fairly direct positive linear relationship between age and BAC level, both for arrested and crash-involved drivers. Only at the extremes of the BAC distribution is there any evidence of a potential cubic relationship, with drivers with zero alcohol (90% of whom test positive for drugs, according to Phillips, 1995) being a full decade older than drivers at 0.01% BAC, and with a slight trend toward younger drivers at extreme BAC levels. The sample sizes at the upper BAC levels are very small, and these cases may represent heavily alcohol-dependent younger offenders who have not yet died or recovered from their addiction, as may have older heavily alcohol-dependent offenders. Generally speaking, however, younger DUI-involved drivers tend to be at the lower end of the BAC spectrum.

Lower BAC offenders also tend to be relatively more crash involved than arrested, as shown in Figure 5, which compares the proportion of arrested (APS) versus crash-involved (HBD) offenders at each BAC level. Drivers at BAC levels from 0.02% to 0.07% are proportionately more crash involved than arrested, as are offenders from 0.17% and above. At the lower end of the BAC spectrum, it is likely that this overrepresentation is reflective of both the slightly increased crash risk associated with positive BAC levels, as well as the relative difficulty of law enforcement in detecting impaired drivers at low BAC levels (relative to low BAC offenders “self-selecting” into the official DUI statistics by becoming crash involved). Again, these combined California data reflect the overrepresentation of youth and crash involvement at low BAC levels.

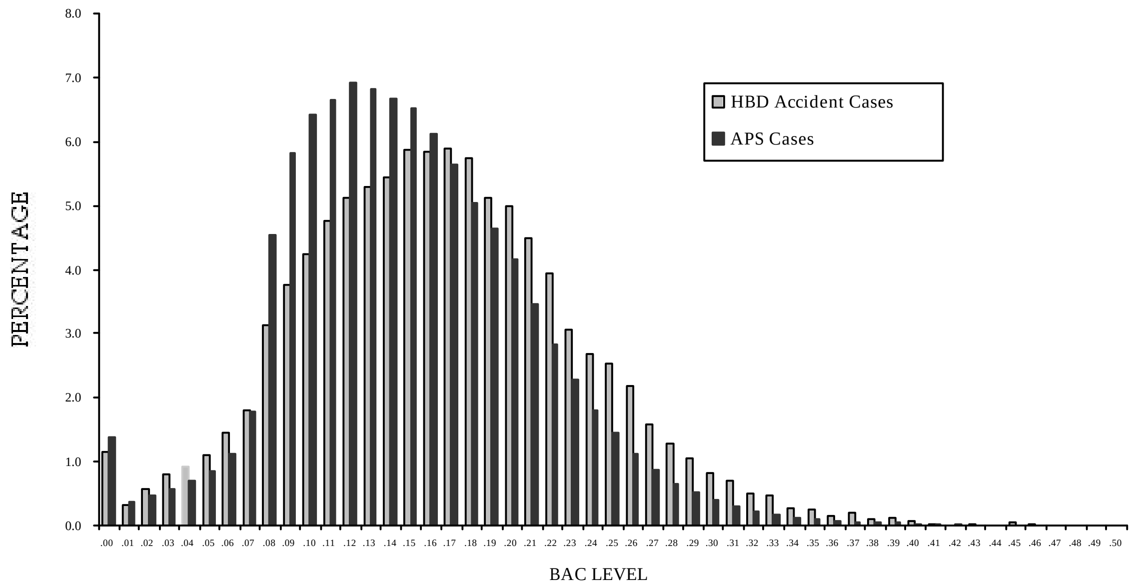

FIGURE 5 Percentage of DUI arrests (APS cases) and alcohol-involved crashes (HBD accident cases) by BAC level.

Based on the 1999 FARS data, male drivers above 0.10% BAC in fatal crashes outnumber females by 2 to 1 (20% versus 10% of all fatal crash drivers). What's more, Zador et al (2000) have documented that, for the 16-20 age group, females have a lower relative crash risk than males, at every BAC level. The FARS data also show that motorcycle and light truck drivers are overinvolved (28% and 20% respectively), while heavy truck drivers are substantially underrepresented (1%). Overall, 17% of all fatal crash drivers showed BAC levels in excess of 0.10%, while an additional 6% showed BAC levels between 0.01% and 0.09%.

In the Grand Rapids study, as BAC level increased, the contribution to crash involvement of any factors other than BAC level began to diminish and disappear altogether, particularly above 0.08%. The relationship between skill/experience and impairment at lower BAC levels has been demonstrated in a number of studies of race car drivers, commercial drivers, and professional pilots, which tend to show that persons highly trained/skilled at a particular task are able to outperform comparison subjects at the same BAC levels (TRB, 1987). Nonetheless, these studies also tend to confirm impairment at relatively low BAC levels, from 0.05% to 0.08%, even for the most highly trained/skilled practitioners.

Coinvolvement of Drugs at Low BAC Levels

One aspect of low BAC level crashes that has not been fully investigated is the coinvolvement of drugs and alcohol. Terhune et. al (1992) found that 17.7% of driver fatalities from a 7-state sample tested positive for drugs other than alcohol. While it has been estimated that perhaps a quarter of all California DUI arrests involve drugs, Phillips (1995) found that 60% of such offenders from 46 counties who had BAC levels of 0.08% or less tested positive for drugs other than alcohol. As the BAC level of DUI arrestees dropped, the proportion of drug positives increased, with 90% testing positive for drugs at zero BAC. These findings have particular significance when considering the epidemiology of crashes at low BAC levels.

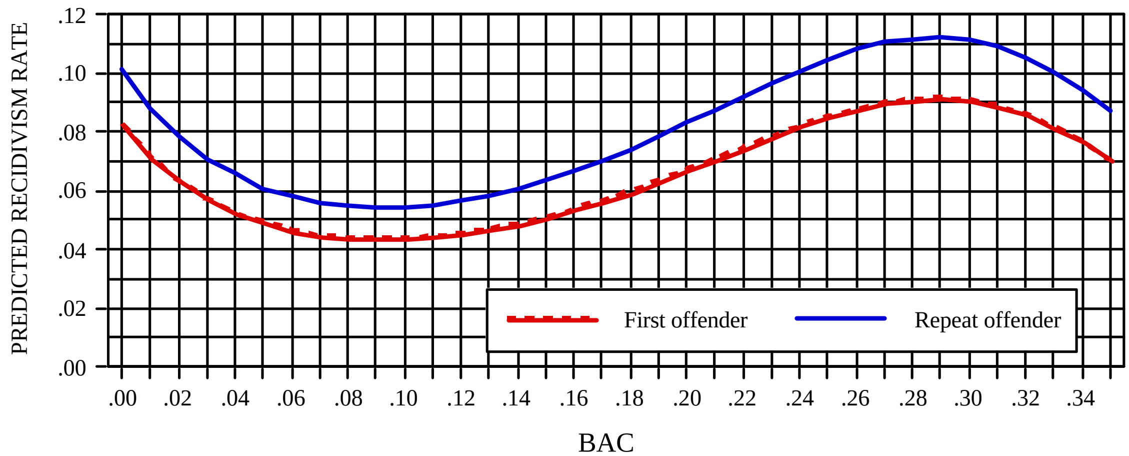

FIGURE 6 Predicted recidivism rate for first and repeat offenders with 1 prior 2-year total conviction (Moskowitz, 1996).

Marowitz (1996) investigated the relationship between BAC level and DUI recidivism, and found that DUI offenders arrested at low BAC levels had among the highest DUI recidivism probabilities. The probability of recidivism was found to be very high for DUI arrestees with zero BAC levels (0.00%), and the rate of recidivism declined as BAC level increased up to about 0.09%. As BAC levels increased from 0.09%, recidivism expectancies also increased, up to about 0.29%, whereupon recidivism risk again decreased with subsequent increases in BAC level. This observed cubic relationship between BAC level and recidivism represented a new "twist" in DUI recidivism prediction, and suggests that low BAC DUI offenders should not be taken lightly in terms of their risk levels.

Alcohol as a Causative Factor in Crashes

While the overall correlation between BAC level and crash risk is clear, the issue of causation is far more problematic to establish. Theoretically, there could be other latent factors which are associated with BAC level which actually are "causing" the increase in crashes. In an effort to gain a clearer picture of the role of alcohol in causing crashes, McCarrol and Haddon (1962) utilized police accident reports to determine the relative responsibility for a crash, by BAC level. Their crash responsibility methodology, applied to a small sample of fatally injured drivers in Manhattan, revealed that drivers at higher BAC levels were more likely to be responsible for their crashes. This methodology was subsequently applied to the Grand Rapids data, and to another small sample from Vermont. The results of these inquiries were summarized by Hurst in Figure 7. These plots show a higher probability of being responsible for a crash as BAC increases, which would tend to corroborate the inference that BAC level is the primary causative factor in these crashes.

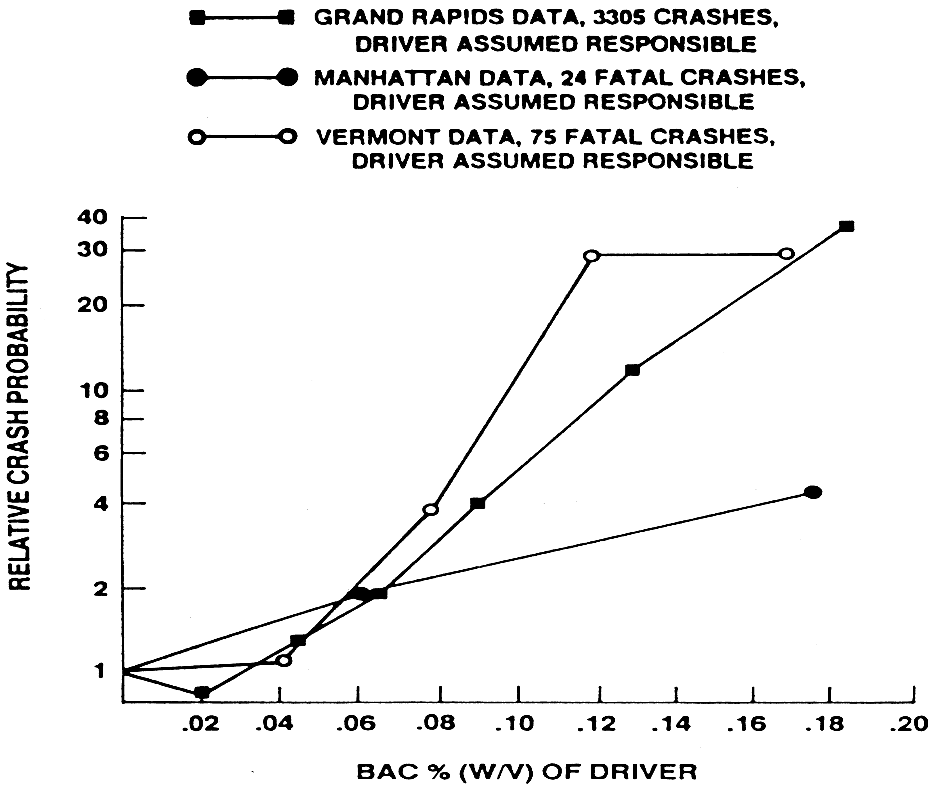

FIGURE 7 Relative crash responsibility for drivers assumed responsible and those not assumed responsible as a function of BAC where 1.0 = relative probability at zero alcohol (Hurst, 1973. Reprinted with permission from the Journal of Safety Research, a joint publication with the National Safety Council and Pergamon Press, Ltd.).

Implications, Conclusions, and Recommendations

Crashes occurring at low BAC levels are generally less serious than crashes at higher BAC levels, ostensibly because drivers are less impaired at lower BAC levels. Research has shown, however, that crash risk increases almost monotonically with BAC level when drinking experience (tolerance) is controlled for, and drivers at even the lowest BAC levels can represent increased risk. Some proportion of this risk, epidemiologically, can likely be traced to an increased likelihood of drug involvement at lower BAC levels. Recent research has shown these very low BAC level offenders to have a high recidivism expectancy, fully as risky as BAC offenders with BAC levels above 0.20%. This relatively new finding has implications for DUI prevention programs and the arrest, adjudication, sanctioning, and treatment of low BAC DUI offenders. Drug offenders may well respond differently to standard drinking driver treatment programs than alcohol-only offenders, and opportunities may exist for alternative sanctioning and treatment of these offenders. The “tailored” treatment approach, which has been promoted for several decades without a great deal of implementation or success, may well make sense with differential diagnosis of drug versus alcohol offenders. Further research on factors which can identify and distinguish the expected recidivism rate of offenders can only aid in directing resources toward these higher risk offenders, and hopefully suggest alternative sanctioning and/or treatment modalities which might more successfully address these elevated risk levels.

The major research need for further exploring the epidemiology of low BAC crashes is improved testing and reporting of BAC levels, particularly of drivers involved in nonfatal injury and PDO crashes. To our knowledge, there is no jurisdiction that routinely obtains BAC readings of drivers involved in all crashes. Given the demonstrably strong relationship between alcohol and increased crash risk, it would not appear inappropriate to require at least preliminary breath testing of all crash involved drivers, and data drawn from these efforts would substantially increase our knowledge of the epidemiology of low BAC crashes. Further research on the characteristics of low BAC crash-involved drivers is needed, along with efforts to distinguish why these low BAC offenders become crash involved, as opposed to other low BAC drivers who do not.

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Epidemiology of Crashes at Low BACs

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Roughly 100 years ago, an article was published identifying alcohol as a causal factor in crashes. Quantifying the relationship between BAC and crashes, however, has been a difficult and contentious matter, as reflected in the four decades of controversy about the dip phenomenon reported in the Grand Rapids study. Some of the methodological difficulties can be understood by examining Table A,taken from the 1999 Traffic Safety Fact which presents the number of drivers involved in crashes by alcohol involvement and crash severity. The second column lists the percentage of drivers in the three crash severity categories who have alcohol present. While 23% of the drivers in fatal crashes have alcohol present, only 5% of the drivers in injury crashes have alcohol present and only 3% of those in property damage only crashes. These large differences in alcohol involvement as a function of crash severity clearly indicate that relative risk curves derived from fatal crashes, injury crashes, and total crashes would differ greatly. Frequent discussions of risk relationships have intermingled data from different crash severity groups. Comparing relative risk estimates as a function of BAC finds higher relative risk curves for fatals and injuries than for all crashes.

Table A
Drivers Involved in Crahses by Alcohol Involvement and Crash Severity

	Alcohol Involvement				
	Yes		No		Total
	Number	Percent	Number	Percent	Number
Drivers in fatal crashes*	13,047	23	43,305	77	56,352
Drivers in injury crashes**	194,000	5	3,573,000	95	3,767,000
Drivers in property-damage-only crashes**	245,000	3	7,125,000	97	7,370,000
Drivers in all crash categories	452,047	4	10,741,305	96	11,193,352

Source: Based on Table 77 from *Traffic Safety Facts, 1999*
*BAC of 0.01 grams per deciliter (g/dl) or greater; NHTSA estimates alcohol involvment when alcohol test results are unknown
**Police-reported alcohol involvement

The increased relative risks for injury and death with alcohol can be explained, in part, by experimental and epidemiological studies which have demonstrated for equated bodily insult that the probability of injury and death rises with BAC level. It has also been suggested, although with less evidence, that alcohol-related accidents involve greater damage. In any case, the relationship between crash probability and BAC level requires examination of all crashes.

Nine controlled epidemiological studies on the relationship between BAC level and crashes, whether all crashes, injury only or fatal only, were found in the literature. Of the nine studies, three were of fatals, three were of injuries, one was of combined total crashes and traffic violations and only two studies dealt with the issue of the relationship between BAC level and relative crash probability.

At the bottom of the table is the number of drivers involved in crashes by alcohol involvement for all crashes. Only 4% of crashes have alcohol involvement. Thus, even if it were assumed that every crash with alcohol involvement was caused by the presence of alcohol, the presence of alcohol would only account for 4% of all crashes. The majority of this table is generated from police reports and there is literature that suggests that police reports underestimate the presence of alcohol. Granting the above, this data indicates a sharp upper limit to the role of alcohol as a causal factor in crashes of perhaps six to eight percent.

The relevance of this finding is not to underestimate the importance of alcohol because as seen, alcohol related crashes have a much higher probability of injury and death. Rather, it is to indicate that performing an epidemiological study to determine the relationship between crash involvement and BAC level, requires controlling for all the other determinants of crash involvement, since these other factors total 92% or greater of the causal factors underlying crash involvement.

The two studies that have been performed on all crashes are the 1955 Toronto, Canada study performed by Lucas, et al. and the 1964 Grand Rapids study by Borkenstein, et al. Unfortunately, the Toronto study is useless to this discussion of low BACs . Based on an earlier study done in Toronto of police evaluation of alcohol involvement in crashes, it was concluded that alcohol had no influence on crashes until approximately .05% BAC. Therefore, the Toronto base comparison group included all drivers with BAC levels from zero to .05%. As you might anticipate, this resulted in a very low estimate for relative crash probability at higher BACs. Only the Grand Rapids Study has applicable data.

Any study relating crash to BAC must control for factors such as the accident site, time, traffic conditions, weather, vehicle age and condition, driver age, experience, drinking practice, education, etc. to mention an incomplete list.

Techniques for controlling these variables include matching crash case and controls by the selection method for obtaining the controls. The Grand Rapids study did not match the crash and control vehicles for accident site, time and direction of travel. The control vehicles were selected by sampling at time and places determined by the preceding three- year history of accident sites. Four drivers were sampled at each control site, regardless of the number of drivers at the study crash sites, leading to overrepresentation of control drivers at single vehicle crash sites.

The Grand Rapids study collected extensive information on the drivers and vehicles, both crash and control, and demonstrated that many of these factors were significant determinants of crash probability. Yet strangely, none of the collected data was utilized in available multiple regression techniques to control for their confounding the extraction of the BAC and crash relationship.

Additionally, both crash and control samples failed to compensate for difficulties in the sampling procedure. Neither hit and run crash drivers, nor drivers who refused to cooperate in the control and crash population were adjusted for, despite the existing evidence that these drivers are more likely than others to have alcohol present.

In a 1966 monograph published by the Road Research Laboratory of the United Kingdom Transport Department, R. Allsop reanalyzed the Grand Rapids data to the extent possible and noted that the study illustrated “the danger of comparing ill-matched groups”. In particular, he demonstrated how the lack of matching or properly controlling led to the erroneous appearance of the dip in relative crash probability at low BACs.

Other researchers, such as Hurst (1973), partially recalculated the Grand Rapids data. Figure A by Hurst demonstrates that controlling the comparison groups for drinking practices results in removal of the purported “dip” and permits uncovering the evidence that any departure from zero BAC increases crash probability.

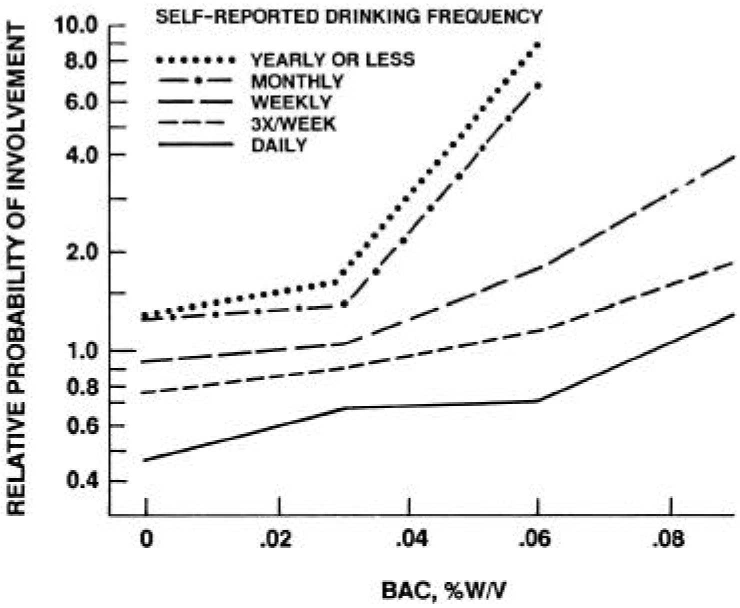

Figure A Relative probability of crash involvement by self-reported drinking frequency (Hurst, 1973). Reprinted with permission from the *Journal of Safety Research*, a joint publication with the National Safety Council and Pergamon Press, Ltd.)

Unfortunately, the total Grand Rapids data set was not available to other researchers who were limited in their ability to simultaneously statistically control for all the variables on which data was collected. Note in the Hurst figure, which partially controls for subject differences in drinking practices, that the five drinking category groups differed by roughly 300% in crash probability at zero BAC. This demonstrates that other major determinants of crash probability remain uncontrolled.

Clearly, determining the crash probabilities associated with lower BACs increases in difficulty as the BAC goes lower. Only by controlling carefully for possibly biased sampling procedures and for the influence of the many factors influencing likelihood of crashes will the true relationship between BAC and crash probability be revealed. To the extent possible, improved statistical analysis of the only relevant study of all crashes, the Grand Rapids study, indicates that no dip in the relative risk curve exists. Crash rates increase with any departure from zero BAC.

The recent study of crash probabilities associated with alcohol executed in Long Beach, California and Fort Lauderdale, Florida attempted to apply lessons from prior studies to the avoidance of bias sampling and to the proper application of controls, both experimental and statistical in data acquisition and analysis. While the report is still being written, it can be stated that the results indicate a positive unimodal curve of increased relative risk with any departure from zero BAC.

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Methodologic Challenges of Assessing Crash Risk among Drivers with Low Blood Alcohol Concentrations

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The sentinel study of high blood alcohol concentrations (BACs) and crash risk in the United States, the "Grand Rapids" study (Borkenstein, 1964), found convincing evidence of the importance of high BACs in crashes. Four decades later, we return to this study as we begin to explore the association between low BACs and crash risk. The "Grand Rapids" days of unquestionably high risk ratios are behind us, and issues of data quality, study design and bias take on increased importance as we turn attention to BACs of 0.05 g/dL and lower. These issues are raised in the papers presented by Robert Foss, Cliff Helander, and Herb Moskowitz. This commentary further explores several of the key issues.

ASSESSING PREVALENCE OF DRIVERS WITH LOW BACS

In his paper, Robert Foss summarizes the findings from five roadside surveys of BAC among drivers in North America. The methodology for conducting roadside surveys is straight forward, and participation rates tend to be very high (e.g., 95%). As illustrated in Figure 1 of the Foss paper, the prevalence of drivers with low BACs and the distribution of low BAC values are generally consistent across the surveys. As a group, these studies support using similar techniques to recruit control drivers (i.e., drivers not involved in crashes) at or near sites where crashes have occurred for studies of BAC and crash risk.

BAC AND CRASH RISK

Data Quality

Studies of motor vehicle crashes often use data from police incident reports of crashes. As with any secondary data source, data quality issues exist. These issues take on increased importance when the strength of the association under study is weak to moderate (e.g., relative risks in the 1.1-3.0 range). Questions regarding data quality in these studies include:

- How complete is the reporting of crashes?
- Does the likelihood of a crash being reported vary by:
  - Severity of crash?
  - Number of vehicles involved?
  - Alcohol involvement?
- How complete is BAC testing among drivers involved in crashes?
- Does the likelihood of a driver being tested vary by:
  - Severity of the crash?

  - Time of day?
  - Sex of the driver?
- Are the procedures to assure accuracy of the data adequate for research purposes?

Questions regarding the likelihood of a crash being reported to the police may be unanswerable. Questions regarding variations in the likelihood of a driver being tested can be answered if the study sample size is large enough to conduct stratified analyses on the important co-factors.

Because the completeness and accuracy of police incidence reports may not be adequate for studying low BACs and crash risk, researchers may need to fund data collection and BAC testing. Researchers may also want to consider restricting the types of crashes included in the study to decrease the potential for “missed cases” to bias the results.

Study Design

The Grand Rapids study (Borkenstein, 1964) used a matched case-control design, matching on location of the crash. This is an efficient design for studying associations for which the outcome of interest is fairly rare, as are motor vehicle crashes. The utility of matched case-control studies for controlling confounding, however, is controversial. (Rothman and Greenland, 1998) When misapplied, matching can introduce confounding where none actually existed. Using a matched design requires: 1) careful consideration of potential confounders during the design phase; 2) evaluation of whether the matched factor(s) was indeed a confounder in the study; and 3) an analytic technique that accounts for the matched design. Rothman and Greenland discuss the advantages and disadvantages of matched case-control designs in Chapter 10 of *Modern Epidemiology* (Rothman and Greenland, 1998).

Controlling for Confounding in the Analysis

In the paper entitled “Epidemiology of Crashes at Low BAC”, Herbert Moskowitz states that performing an epidemiological study to determine the relationship between crash involvement and BAC level requires controlling for all the other determinants of crash involvement. This statement is misleading. Indeed, it is necessary to collect information on other determinants of crash involvement (and determinants of BAC) and assess whether they confound the association under study (BAC and motor vehicle crashes). Factors that are associated with crash risk but not with BAC, or visa versa, do not confound the association between BAC and crash risk. Controlling for these factors will reduce the precision of the risk estimate and, in some cases, may bias the risk estimate. To accurately estimate the association of BAC to crash risk, researchers must collect information on potential confounders, and conduct a stratified analysis to assess whether these factors actually confound the association under study before moving on to multivariate analyses.

CONCLUSION

Epidemiology is a powerful tool for understanding risk factors for injury. Applying observational study designs to understand the association between low BACs and crash risk, however, may test the limits of epidemiologic techniques. Sources of bias that would have little effect on the study of high BACs and crash risk could materially distort findings in studies of low BACs and crash risk. Issues of data quality, study design and bias warrant careful consideration as we seek to understand the effects of BACs of 0.05 g/dL and lower on driving.

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Comment on “Effects of Low BACs”

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PREVALENCE OF DRIVERS AND DRINKERS WITH LOW BACS

Rob Foss’s paper, “Prevalence of Drivers and Drinkers with Low BACS,” was an excellent paper that lays the foundation for how frequently we find drivers (and drinkers, in general) with low blood alcohol concentrations (BACs), defined as .05 g/dl or less. The evidence shows, in fact, that most drivers on the roads with positive BACs are at these low levels.

Several roadside surveys conducted in the last 10 years where drivers were tested for BAC were summarized. While the results of the National Roadside Survey conducted in 1996 have been well publicized, the details of the other 4 studies described (OH, MN, NC, BC) are not as well known. Comparing the results of the five surveys was very useful and revealing. In general, the results of these surveys were consistent in the proportion of drivers out there on our roadways who are at these low BACs.

The new data presented on the North Carolina college student drinking survey raises some important issues:

- Figure 8 showing the mean BAC of these students according to the number of drinks they said they consumed is very interesting. Is gender and body weight available for more detailed analyses to see if that plays a role? Those analyses might be useful.
- The issue of number of drinks and estimating one’s BAC is important as more states pass .08 BAC laws. More information is needed by the public on this topic.

Obstacles for police using passive alcohol sensors was alluded to twice in the paper. It might be useful to discuss some of these obstacles and see how many can be overcome. It is readily apparent that passive alcohol sensors can be very important in the future for police to detect low BACs in drivers stopped for various traffic violations, at sobriety checkpoints, and particularly for zero tolerance enforcement for underage drivers. While police seem reluctant to use passive sensors, studies show that police miss about half of drivers stopped at checkpoints who are at BACs of .08 or greater.

In Figure 1, the percent of alcohol positive drivers from the National Roadside Survey of 1996 appears to be shown as 19%. The survey report (Voas, et al, 1998) shows that figure at 16.9%.

Finally, it appears from roadside surveys that low BAC drivers are similar to zero BAC drivers in some respects (seat belt usage) and similar to high BAC drivers in other respects (age, gender). Are they similar to low BAC drivers involved in fatal crashes? If not, in what respects are they different? Are some drinking drivers just on a continuum (i.e. sometimes at low BACs, sometimes at high BACs)? These are some of the questions we must address to further assess the low BAC driver situation.

EPIDEMIOLOGY: CRASHES AT LOW BACS

Cliff Helander's paper, "Epidemiology: Crashes at Low BACS," was a relatively thorough review of past studies on crash risk at various BAC levels. Alcohol involvement from fatal crash data and past research on alcohol as a causal factor in crashes was also discussed.

The author makes excellent points about possible other drug involvement for drivers in crashes at low BACs and drivers arrested for DWI or DUI at low BACs. The higher recidivism rates for convicted drivers at low BACs certainly indicates the possibility of other substance abuse problems. This is something we need further data on.

In Figure 5, wouldn't one expect to get lower frequencies of low BACs for drivers arrested for DUI compared to drivers in crashes because of the nature of the arrest process? Drivers with low BACs are typically not arrested for DUI because they are not over the illegal limit, unless other drugs are suspected.

In the discussion of alcohol and crash culpability, a study by Terhune and Fell (1982) showed that injured drivers with BACs>=.10 were culpable for their crash 74-90% of the time. This compares to cupability rates of 54-69% for drivers with lower BACs (<=.10) and 34-43% for drivers with no alcohol or drugs. Other studies have shown similar results.

One of the compelling questions concerning the data presented in this paper is why alcohol involvement is substantially higher in more severe crashes. Is it because of the gross underreporting of alcohol by police in property damage only crashes? Or is it because driver alcohol impaired crashes involve higher speeds? Or less avoidance by the drivers? Or because of the potentiating effect that alcohol has on injury? We really need to know more about this phenomenon.

EPIDEMIOLOGY OF CRASHES AT LOW BACS

Herb Moskowitz's paper, "Epidemiology of Crashes at Low BACS," reviewed 9 "controlled" epidemiological studies on the relationship between BAC level and crashes. It dismisses 6 studies that dealt only with injury or fatal crashes and 2 other studies due to various methodological problems. This leaves the 1964 study in Grand Rapids by Borkenstein. Many problems with the methodology and data in the frequently referenced and often misunderstood Grand Rapids study are discussed by the author and are very enlightening.

The data in Table A from NHTSA should have included caveats about the gross underreporting of alcohol in injury and property damage crashes by police. This is well known. Other studies where injured drivers in crashes were actually tested for BAC reveal alcohol involvement rates on the order of 15-25% for these crashes (for example, see Terhune and Fell, 1982). The rate of alcohol involvement in injury crashes, and certainly serious injury crashes, approaches that of drivers in fatal crashes. In this respect, Table A is very misleading.

A recent study using FARS data and the National Roadside Survey of 1996 data (Zador, et al, 2000) has, indeed, calculated relative risks of driver involvement in fatal crashes for low BAC levels. Depending upon driver age and gender, these risks for drivers at BACs = .02-.05 are anywhere from 2 to 5 times that of drivers with no alcohol. It is surprising this study was not discussed in any of the papers. There are some issues with the methodology used in the Zador study, but the information is very useful to policy-makers.

CONCLUSION

As a final note, in determining policy, it is usually the cumulation of evidence that determines BAC legal limits. Policy is not based upon one study or one threshold of the various risk levels. The more information we accumulate on low BAC drivers, the better off we will be on deciding whether lower legal limits are justified. In my opinion, we do not have enough information to make that determination, at least based upon the epidemiological research alone. Information about decrements in driving performance at low BACs using state-of-the-art driving simulators and on-the-road testing will be very important in this policy decision about low BACs.

On a personal note, I also believe it is not enough for us, as researchers, to merely conduct and publish good research. We must communicate the results and implications of that research to policy makers. We must make the research results understandable to the advocates and activists at the grassroots level. There will be great resistance from certain factions of society to lower the BAC limits further than .08 BAC. If our research supports lower limits, we must carefully craft it so that policy makers can use it.

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Risk of Harm Associated with Low BACs: Lessons Outside the Highway

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INTRODUCTION

The purpose of this paper is to summarize what is known about the effects of low blood alcohol concentrations (BAC) on non-highway risks, in particular that of operating boats and other vessels on the water. It presents findings from studies that focus on actual measurement of BAC and not self-reported drinking as a risk factor. We compare relative risks for drinking and aquatic activities to those from drinking on the highway and with other factors such as speed and fatigue, where studies enable direct comparisons. We did not consider it possible to compare studies of other risk factors, such as cell phone use while driving, as no comparable studies of alcohol using the same methodological approaches could be found in the literature. Outside the extensive work done investigating alcohol risks while driving (both in the laboratory and on the highway)(e.g. Moskowitz 2001 a&b), there is surprisingly little work done on alcohol risks in other settings such as water transportation.

Many studies of the effects of low BACs have examined the effect of low BAC levels on human performance and these are summarized in other papers presented at the workshop. Similarly, a number of the studies of motor vehicle crash risks and BAC include estimates of relative risk of crashing at low BACs. Our paper will not discuss these studies, as most are covered in other papers from this workshop. Unfortunately, as noted in the accompanying commentary by James Hedlund, the results from the recent replication of the Grand Rapids study that sought to examine the specific question of crash risk on the highway at low BACs are still embargoed, and thus could not be shared with participants. However as noted by Hedlund, Herb Moskowitz commented during discussions at the workshop that their recent study also found an increased crash risk at the lowest BACs.

RECREATIONAL BOATING

Recreational boating is a popular pastime, with over 43 million people reporting they either operated or rode in a motorboat in 1994 and results in more than 800 fatalities annually (Logan et al,1994; US Coast Guard, 2000(a)). Alcohol is commonly involved in boating, drowning, and other unintentional injury fatalities (Smith et al, 1999; Mengert et al, 1992; Howland et al, 1995; Smith & Kraus, 1988; Canadian Red Cross Society, 1999; Lunetta et al 1998). While the risks of drinking and driving on roadways are well understood, little is known about the risks of drinking in other environments, such as when boating. However, alcohol use is increasingly being recognized as an important factor in many boating fatalities (Smith et al, in press). One study with high testing rates found that 51% of boating fatalities had a BAC of 40mg/dl or higher, and 30% were over 100mg/dl (Mengert et al, 1992; US Coast Guard, 2000(b); Hoxie et al, 1988). Alcohol involvement is similar to those of automobile driver fatalities. Although these and other studies suggest that alcohol increases the relative risk of dying while boating, they do not adequately address whether the risks while boating are similar to those on the highway (Smith et al, in press).

Current public policy to prevent alcohol-related boating deaths and injuries has focused on the boat operator and adopted similar approaches and laws as that for impaired driving. There are also widespread perceptions that boating is safer than driving an automobile (Howland et al, 1993; Stiehl, 1975). Unfortunately, these laws and beliefs are inconsistent with the nature of boating fatalities and fail to recognize that passengers can put themselves at risk regardless of the actions or alcohol use by the operator. The Coast Guard reports, for example, that only about half the fatalities can be attributed to operators. Most boating fatalities involve drowning; only 18% involve collisions with other boats or objects. Falls overboard are the leading cause of fatalities and almost half (46%) of these occur when the vessel is not underway (Howland et al, 1993). Alcohol use not only affects the probability of ending up in the water, but also affects the probability of survival once a person enters the water. Due to this apparent double jeopardy, it has been suggested that alcohol use may actually be more hazardous on a boat than in a motor vehicle on the highway, with even low BACs greatly increasing risk for adverse outcomes (TRB, 1986; Wright, 1985; Howland et al, 1993). However, there was little empirical documentation for this.

We recently published a study, which sought to better define the relationship between alcohol use and the risk of death while boating, adjusting for known or potential risk factors for drowning and other boating deaths (Smith et al, in press). This large population-based case-control was conducted in two states (Maryland and North Carolina), which include a wide variety of types of waterways on which recreational boating takes place. We also examined whether low BAC levels pose a significant relative risk and whether risks are different for passengers and operators. Boating deaths from 1990-98 were compared with controls obtained from a stratified random sample of boats from waterways in each state. In contrast to the Coast Guard definition of a boating death (US Coast Guard, 2000(a)), individuals who drowned after using a boat as a platform for swimming were included in the study. Interviews and a self-administered questionnaire were given to the operator and two random passengers, followed by a breath sample. More complete details of methods can be found in our paper.

Of the 253 boating victims meeting inclusion criteria for this case-control study, 15 (6%) were excluded from the analysis because they were recovered more than one week after death (4%), or had unknown recovery time (2%). If bodies are not recovered early, endogenous alcohol production can inflate BAC (Levine et al, 1993; Wintemute et al, 1990; O'Neal & Poklis, 1996). We developed adjustments of BAC (1-40mg/dl) to account for this in cases recovered after 12 hours and before one week (Hadley and Smith, 2001). Only 7% of potential cases were not tested for alcohol, and of the 221 cases included in the study, 55% had a positive BAC (adjusted for recovery time); 36% were >50 mg/dl, 27% were > 100 mg/dl, 18% were >150 mg/dl, 11% > 200mg/dl and 7% > 250mg/dl. Sixty-eight percent of passenger fatalities and 48% of operator fatalities had a positive BAC ($p < .001$); and 37% of passengers and 27% of operators had a BAC > 100mg/dl ($p = .04$).

Almost all of the operators of boats sampled for the control survey agreed to participate (93%), resulting in 3943 controls (passengers and operators) with valid breath sample. The relative risk of death by BAC level among those who used alcohol, compared to those who did not, was adjusted for age, race, gender, occupant status, boat type, location, time-of-day, weekend/weekday, and included weights for differential passenger selection probabilities. The relative risk of death was increased even at low BACs with OR= 1.3 (95% CI 1.2-1.4) for BAC of 10 mg/dl, increasing to a maximum odds ratio of 44 at 260 mg/dl (OR= 44, 95% CI 22-90) (Figure 1), with no significant difference for only those persons meeting the official Coast Guard definition of boating accidents. Section 4 of this paper discusses how these risks compare to driving. Additional analyses using BAC ranges found that even at BAC levels of 1 to 49 mg/dl, risks are increased (OR=3.4, 95% CI 2.2-5.1) and BACs of 150 mg/dl or greater were associated with a 34-fold increased relative risk. The adjusted odds ratio for all BACs > 50 mg/dl was 16.6 (95% CI 11.8 – 23.2); for BAC > 80 mg/dl, it was 14.6 (95% CI 10.2 – 20.9), and at BAC > 100 mg/dl, it was 20.6 (95% CI 13.9 – 30.6).

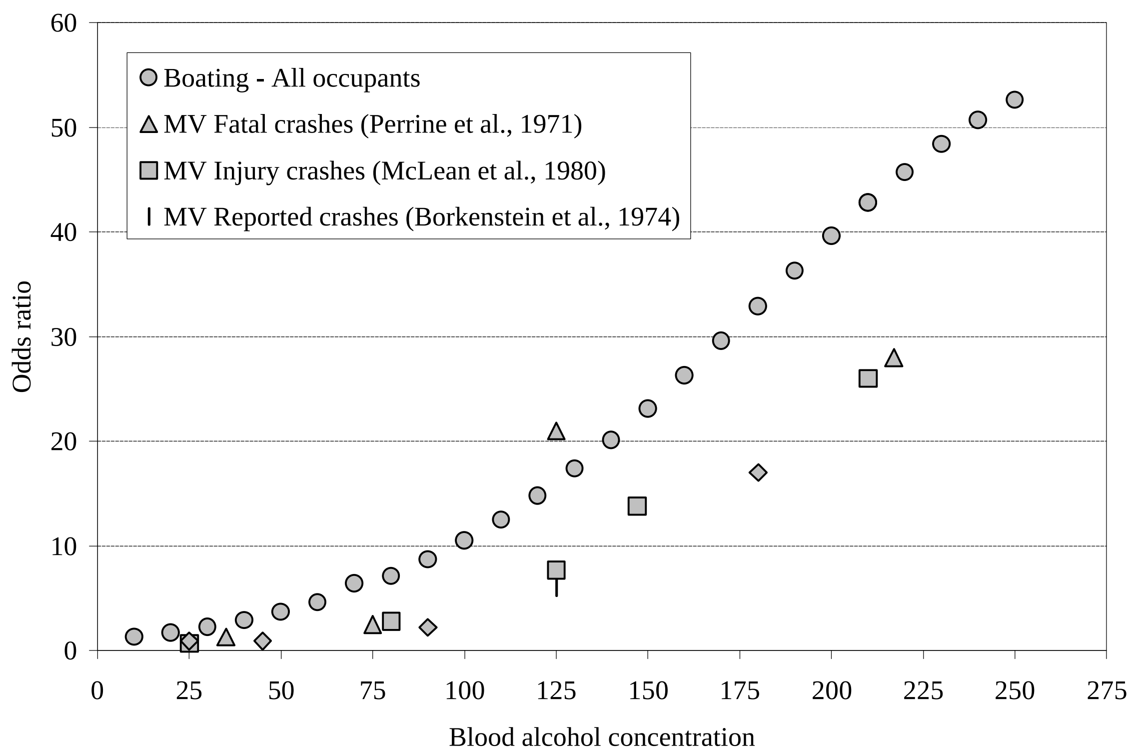

FIGURE 1 Comparison of relative risks for boating fatality by BAC, with comparable relative risks for motor vehicle studies.

The nature of the curve showing the relationship between relative risk of death and BAC was not statistically significantly different between operators and passengers, males and females, white and black persons, and among persons of different ages, or in different types of boats indicating no effect modification. Risks were the same for passengers and operators adjusting for other factors and adjusting for potential refusal bias in controls. More complete results can be found in our original paper.

Study Implications

The relative risk of death was significantly elevated at all non-zero BAC levels. Even at the lowest BAC level of 10mg/dl point estimate and at BAC range, 1-49mg/dl, there is a substantially increased risk of death. Our finding are consistent with experimental studies which show that low BACs increase self-confidence, decrease inhibitions, and impair performance, both in the laboratory and in simulated situations for driving and flying (Laurelle, 1977; Council on Scientific Affairs, 1986; Moskowitz et al (a&b), Toronros, 1991; Morrow, 1991 & 1993; Yesavage, 1994; Taylor et al, 1994). In addition, recent maritime studies of simulated commercial ship operations (see Section 2) found significant impairment in the ability to control a ship at BACs below 50mg/dl (Howland et al, 2000 & 2001).

MARITIME TRANSPORT AND SIMULATED SHIP-HANDLING PERFORMANCE

Under current U.S. Department of Transportation (DOT) regulations, aircraft pilots, commercial truck drivers, railroad engineers, and merchant seamen, are subject to sanctions (e.g. revocation of license) for operating their respective vehicles at or above blood alcohol concentrations (BACs) of 0.04 gm%. Truck drivers, railroad engineers, and merchant seamen are prohibited from using alcohol within four hours prior to operation of their vehicles; aircraft pilots are prohibited from using alcohol within eight hours prior to flying. Truckers and railroad engineers are prohibited from operation of vehicles with any measurable blood alcohol (defined as 0.02 gm% BAC or above). In 1987 (effective 1988), the Coast Guard established both behavioral measures and BAC standards regarding alcohol (0.04 gm% for commercial boaters). Under current regulations, however, it is unclear whether merchant seamen may operate commercial vessels at BACs less than 0.04 gm%, although individual shipping companies may have policies in this regard (Howland et al, 2000 & 2001).

Commercial shipping encompasses freighters and tankers involved in international trade as well as domestic vessels functioning as fishing boats, tugboats, coastal transports of various kinds, dredges, ferries, tour boats, water taxis, harbor launches (carrying more than six passengers), and gambling and cruise vessels. Injury resulting from the impaired operation of a commercial vessel can occur in several ways. The operator can injury his/her self, or passengers, as a result of a crash with another vessel or object. Or, injury can result through an extended causal chain as, for example, when a tugboat destroys a railroad bridge when there is an approaching passenger train (Alabama, 1995) or when a large commercial vessel strikes a public facility such as a waterside shopping and entertainment development (New Orleans, 1996). Our research team has recently published two pilot studies on the effects of low BAC on simulated merchant ship handling (Howland et al, 2000 & 2001).

Simulated Operation of a Commercial Vessel's Power Plant

Our first study examined the effects of low dose alcohol (between 0.04 and 0.05 g% BAC) on maritime cadets' performance on simulated operation of a commercial vessel's power plant (main engines and electrical generating systems (Howland et al 2001). This study used a randomized balanced placebo design in which alcohol administration (vodka and tonic vs. tonic only) was fully crossed with the expectancy that alcohol is administered (told receiving alcohol vs. told receiving tonic only). Following a baseline trial on day 1, on day 2 participants were randomized to expectancy (told alcohol or placebo) and beverage (receive alcohol or placebo). The alcohol dosage was 0.6 g/kg for males and 0.5 g/kg for females, and was targeted to produce a BAC of 0.04 gm%, as that is the legal limit for operation of a commercial vessel under current federal law. The study was conducted at the Massachusetts Maritime Academy, Buzzards Bay, MA. Participants were 18 volunteer engineering students in their senior year, at least 21 years of age, with previous experience on the diesel simulator. After a 35-minute consumption and absorption period, each cadet operated a computer-controlled power plant simulator that replicates the instrumentation used to monitor a large modern vessel's engines and electrical generating systems. This simulator can be programmed to create problematic circumstances (e.g., failure of a fuel pump) and measures performance with respect to the diagnosis and response to the problem. In both baseline and performance days, participants were randomized to one of four diesel simulator scenarios, each replicating a system failure in a power plant subsystem (e.g. main propulsion, electrical generating). Different, but comparable scenarios were used for the first and second trials. For each trial, a system failure was simulated and the time required to identify the failure and take effective remedial action was measured. Performance was measured by time required for problem identification and remediation. Time to restore the power system to normal conditions was the main outcome measure (shorter time equated with better performance).

A main effect for alcohol administration was found. In the alcohol condition, simulator performance time was almost twice as long (351 sec) as on the placebo condition (186 sec). Under the placebo-placebo condition, the time increased by 5% from a mean of 263.6 seconds at baseline to a mean of 278.2 seconds at the performance trial. Under the placebo-alcohol condition, the time increased by 200%, from 124.1 seconds at baseline to 350.8 seconds at the performance trial. Using ANCOVA, the main effect for beverage was significant at $p=0.05$, with a large effect size ($f = 0.71$). Neither expectancy nor the interactions of beverage by expectancy were significant.

Bridge Simulator Study

This second study examines the effects of alcohol (between 0.04 and 0.05 g% BAC) on simulated merchant ship handling using a bridge simulator (Howland et al, 2000). Otherwise the research design was similar to the aforementioned study. Two-group randomized factorial design was used to compare beverage alcohol to placebo while controlling for baseline performance on a previous day. The study was conducted in the Maritime Simulation Center at Maine Maritime Academy, Castine, ME. Participants were 38 volunteer deck officer cadets in their junior or senior year, at least 21 years of age, with previous experience on a bridge simulator. Following a baseline trial on Day 1, on Day 2 participants were randomized to receive alcohol (0.6 g/kg for males and 0.5 g/kg for females) or placebo. The characteristics of participants were similar except for BAC (Table 1). After allowing time for absorption, participants completed a bridge simulator task. For baseline and performance trials, participants were randomized to one of four bridge simulator scenarios, each representing passage of a fully loaded container vessel through a channel with commercial traffic. Simulator scenarios involved conning a fully loaded container ship through the entrance to the port of Halifax (NS) under conditions of heavy traffic and fog. Each scenario lasted for approximately 25 minutes. Subjects used visual and radar observations to direct a helmsman (a non-subject experienced seaman blinded to subjects' experimental condition) who executed orders with regard to course and speed. Radio communications with shipping traffic were simulated by having an experienced officer respond to the subject's radio hails. Neither varied throughout the exercises. During the thirty-five minute absorption period, subjects were given written orders outlining the locations, expected conditions (e.g., weather forecast), and objectives of the exercise and were permitted to plot courses on charts provided. Scoring was done on the basis of predetermined performance components, such as timely and appropriate communications with other vessels, remaining within the channel, not striking another vessel or channel marker, timely operation of fog horn, appropriate speed and steering orders, etc. The aggregate scenario score given by blinded maritime educators measured overall performance. Scoring ranged from -50 (worse performance) to 165 (perfect performance).

TABLE 1 Characteristics of Participants in Study of Simulated Merchant Ship Piloting

	Alcohol Group	**Placebo Group**
N	19	19
Mean (S.D.) age	23.3 (5.0)	22.5 (2.0)
Male (%)	84	95
Mean BAC	Start of test 0.047 g% BAC	0.0 g% BAC
	End of test 0.051 g% BAC	0.0 g% BAC
Mean (S.D.) number of times drank in last 30 days	5.8 (1.2)	5.7 (1.1)
Mean (S.D.) number of drinks consumed on typical drinking day during past 30 days	3.8 (1.6)	4.4 (2.5)
Mean (S.D.) number of times high in the past 30 days	5.9 (1.2)	5.7 (1.2)

*All comparisons (except BAC) were non-significant

A main effect for alcohol was found indicating that performance was significantly impaired by this low dose of alcohol relative to performance in the placebo condition. The alcohol-dosed group's score were 21% lower on average than those receiving the placebo.

Significance of Findings from Simulated Marine Operations

The results from both of these studies support our hypothesis that alcohol exposure at the current federal legal limit has significant degrading effects on commercial ship handling performance. To our knowledge, these are the first experimental studies examining the effects of alcohol on simulated ship handling. Whether these outcomes are generalizable to experienced seamen is not known but this question is included as part of an ongoing study. Further research is required to determine effects at lower BACs. Our findings are also consistent with current federal regulations that limit low-dose alcohol exposure for the operators of commercial transport vehicles. It is noteworthy that the process of monitoring a ships power plant is similar, in many respects, to the process of monitoring any large power plant, including that of a nuclear reactor. These studies take advantage of the availability of sophisticated work-task simulators located in regimented institutions to conduct rigorous research on alcohol's effects on occupational performance. The results of the studies are likely to be generalizable to a broad range of occupational and non-occupational venues.

COMPARISON OF ALCOHOL AND OTHER RISK FACTORS

Speed

The increased relative risks from speeding have been compared to those of alcohol in one case-control study conducted in Adelaide Australia (Kloeden et al 1997). The study first examined the relationship between traveling speed and the risk of involvement in a casualty crash (defined as requiring an ambulance to be called), for sober drivers of cars in 60 km/h speed limit zones in the Adelaide metropolitan area. The speeds of cars involved in casualty crashes were compared with the speeds of cars not involved in crashes but traveling in the same direction, at the same location, time of day, day of week, and time of year. The selection of case vehicles was designed such that valid estimates could be made of the relative risk of a car traveling at a free speed in a 60 km/h zone becoming involved in a casualty crash compared to the risk for a car traveling at the posted speed of 60 km/h during the hours of 9:30 a.m.-4:30 p.m., Monday to Friday, as these times had the highest number of non-alcohol-related crashes in Adelaide (some cases were also collected at nights and on weekends). The pre-crash traveling speeds of the case vehicles were determined using computer-aided accident reconstruction techniques which include detailed investigation of each crash at the scene, and enabled them to calculate what the results of the crash would have been if the case vehicle had been traveling at a different speed. In addition to the speed study, a separate study was set up to measure the relationship between blood alcohol concentration and traveling speed. The speed of an approaching car was measured 200-300 metres before a signalized intersection using a laser speed meter. When the car stopped at this intersection for a red light, the driver was approached and asked to blow into a breath alcohol meter. No other information was collected from the driver.

Cars involved in casualty crashes were generally traveling faster than cars that were not involved in a crash: 68 per cent of casualty crash involved cars were exceeding 60 km/h compared to 42 per cent of those not involved in a crash. The difference was even greater at higher speeds: 14 per cent of casualty crash involved cars were traveling faster than 80 km/h in a 60 km/h speed zone compared to less than 1 per cent of those not involved in a crash. Speeds below 60 km/h had the same risk of involvement in a casualty crash as those at 60 km/h. Above 60 km/h there is the risk of involvement in a casualty crash increased exponentially with increasing traveling speed. The risk approximately doubled with each 5 km/h increase in traveling speed.

Separate calculations estimated that nearly half (46 per cent) of these free traveling speed casualty crashes probably would have been avoided, or reduced to non-casualty crashes, if none of the case vehicles had been traveling above the speed limit. A more conservative estimate, based on calculation of stopping distances and impact speeds, suggested that 29 per cent of crashes would have been avoided altogether, with a reduction of 22 per cent in the impact energy of the remaining cases.

A more conservative analysis estimated that a 10 km/h reduction in the traveling speeds of the crash involved cars would have resulted in a reduction of at least 42 per cent in the number of crashes. A 5 km/h reduction showed much less effect but would still have resulted in a reduction of at least 15 per cent in the number of crashes. An earlier study using a similar design in Adelaide raised concerns that alcohol use may confound the relationship with speed. (More et al 1900) A comparison of the relationship between free traveling speed and the driver's blood alcohol concentration (BAC) in this new study however showed that higher BAC levels are associated with only slightly higher traveling speeds and the average difference in speed was less than three kilometers per hour. The authors concluded that the risk of involvement in a casualty crash is twice as great at 65 km/h as it is at 60 km/h, and four times as great at 70 km/h, and that even modest reductions in traveling speeds could greatly reduce crash and injury frequency. In a 60-km/h speed limit area, they estimated that the risk of involvement in a casualty crash doubled with each 5-km/h increase in traveling speed above 60 km/h.

In order to compare the effect of speed with alcohol, the authors used data from their earlier case-control study of crash risk and BAC that was conducted in 1979 (McLean et al., 1980). Although not done at the same time, comparable case-control studies on speed and alcohol have not been conducted elsewhere. They found that the relative risk of involvement in a casualty crash at 72 km/h is similar to that for a BAC of 0.12 (Table 2). They concluded that speeding in an urban area is as dangerous as driving with an illegal blood alcohol concentration. Traveling at 5 km/h above the 60 km/h limit increased the risk of crash involvement as much as driving with a blood alcohol concentration of 0.05. The authors also noted that the penalty for the BAC offence is a $500-$900 fine and automatic license disqualification for at least six months while the penalty for the speeding offence is only a $110 fine. While this study provides an interesting comparison, the studies of alcohol and injury risk are rather crude and did not allow adjustment for any confounders.

TABLE 2 Comparison of Relative Risks of Involvement in a Casualty Crash for Speed and Alcohol, Adelaide, South Australia

Speed		Alcohol	
(km/h)	Rel. Risk	(g/100mL)	Rel. Risk
60	1.0	zero	1.0
65	2.0	0.05	1.8
70	4.2	0.08	3.2
75	10.6	0.12	7.1
80	31.8	0.21	30.4

Sleep

Sleep deprivation has been shown to have similar effects on performance to that of alcohol. Several studies have examined the relative effects on performance of sleep deprivation and alcohol in laboratory settings. In one study, performance effects were studied in the same subjects over a period of 28 hours of sleep deprivation and after measured doses of alcohol designed to bring subjects BAC up to about 0.1% (BAC)(Williamson et al, 2000). They used 39 subjects, 30 employees from the transport industry and nine from the army. After 17-19 hours without sleep (corresponding to 2230 and 0100) performance on some tests was equivalent or worse than that at a BAC of 0.05% (Table 3). Response speeds were up to 50% slower for some tests and accuracy measures were significantly poorer than at this level of alcohol. After longer periods without sleep, performance reached levels equivalent to the maximum alcohol dose given to subjects (BAC of 0. 1%).

TABLE 3 Equating the Effects of Sleep Deprivation and Alcohol Consumption

	Hours (decimal) of Wakefulness Equivalent to BAC Conccentrations					
	BAC 0.05%			BAC 0.1%		
Test and Measure	**Mean**	**95% CI**	**%***	**Mean**	**95% CI**	**%***
Reaction time task:						
Speed (ms)	18.0	17.1-19.0	76	18.7	17.6-19.9	64
Accuracy (misses)	17.3	16.5-18.1	42	17.7	16.5-19.0	45
Dual task:						
Speed (ms)	17.3	16.8-18.7	84	19.7	18.6-20.8	67
Hand-eye coordination (level of difficulty)	18.4	17.4-19.5	79	19.4	18.4-20.4	58
Tracking task:						
Hand-eye coordination (level of difficulty)	18.3	17.4-19.1	74	19.0	18.9-20.0	61
Mackworth clock vigilance:						
Speed (ms)	17.1	16.2-18.0	82	18.1	16.9-19.4	58
Accuracy (misses)	17.6	16.7-18.6	68	18.8	17.9-19.7	76
Symbol digit task:						
Speed (ms)	18.6	17.4-19.7	50	18.9	17.9-19.9	48
Speed (symbols inspected (n))	18.5	17.5-19.6	57	18.6	17.7-19.6	79
Accuracy (correct %)	16.9	15.7-18.1	41	18.4	17.0-19.8	42
Spatial memory task:						
Accuracy (length of Recalled sequence)	18.1	17.1-19.0	86	17.9	16.9-18.8	64

*Numerator=number of subjects contributing data; denominator=number of subjects whose range of BAC incorporated 0.05% (n=37 or 38) or 0.1% (n=33).

Amount of sleep deprivation required to produce performance decrements equivalent to varying concentrations of blood alcohol (BAC), and the time of day at which the equivalence occurred in this study.

A more recent study by the same group compared the effects of 28 h of sleep deprivation with varying doses of alcohol up to 0.1% blood alcohol concentration (BAC) in the same subjects (Williamson et al 2001). Twenty long-haul truck drivers and 19 people not employed as professional drivers acted as subjects for the laboratory study. Tests were selected that were likely to be affected by fatigue, including simple reaction time, unstable tracking, dual task, Mackworth clock vigilance test, symbol digit coding, visual search, sequential spatial memory and logical reasoning. While performance effects were seen due to alcohol for all tests, sleep deprivation affected performance on most tests, but had no effect on performance on the visual search and logical reasoning tests. Some tests showed evidence of a circadian rhythm effect on performance, in particular, simple reaction time, dual task, Mackworth clock vigilance, and symbol digit coding, but only for response speed and not response accuracy. Drivers were slower but more accurate than controls on the symbol digit test, suggesting that they took a more conservative approach to performance of this test. Another outcome from the study was that it demonstrated which tests are most sensitive to sleep deprivation and fatigue and established a set of tests that can be used in evaluations of fatigue and fatigue countermeasures. These maybe useful for studies of low BAC effects. Fatigue caused by of sleep deprivation is an important factor likely to compromise performance of speed and accuracy of the skills needed for safety on the road and its efforts are similar to those due to alcohol.

COMPARISON OF BOATING AND DRIVING

A comparison of risks of fatality associated with different levels of BAC from our boating study to those for motor vehicle crashes as computed by Hurst (1985)from classic studies found increased relative risks for boating compared to driving (Borkenstein et al, 1974; McLean et al, 1980; Perrine et al, 1971)(Figure 1). The overall fatality relative risk for boating associated with alcohol use is higher than those found in motor vehicle crash risk studies. Our risk estimate for operators, the group most analogous to car drivers, is the same as those for passengers. As the severity of the crash increases the difference in relative risk is reduced. The discrepancy in relative risks for boating are greatest with police reported crashes (Borkenstein et al 1974) and less so when compared to injury crashes (McLean et al 1980). We note however, that most case-control studies of alcohol risk using actual BAC measurements (even among motor vehicle drivers) provide only crude estimates of BAC risk unadjusted for other factors. We found few studies of alcohol and motor vehicle fatality risk that attempted to adjust for potential cofounders (Perrine & Smith, 1991, Zador et al, 2000). The study by Zador (2000) found risk estimates for high BAC levels that are much higher than those from more traditional case control studies. That study however, may not be comparable with others as it included only weekend nights (10 p.m. - 3 a.m.) and no summary risk estimates (only stratified by gender and age). Furthermore, its risk estimates for high BAC levels may be artificially high as the national survey from which controls were selected may under represent rural areas. In addition, the model used in the analysis imposed a constant increase in risk for each incremental increase in BAC level, in effect forcing estimates to show an exponential increase in risk. Our study, for example, found that the relative risk was better described as a second-order term including BAC and BAC2 in the same model for calculating the curve (Figure 1).

CONCLUSIONS

The evidence that boating fatality risk and error rates in simulating shipping increases significantly, even at low BAC levels, suggests that relative risks of death, injury or crash may actually be higher than on the highway. Simply adopting per se BAC limits from motor vehicle laws to proscribe alcohol levels for boat operators (both recreational and commercial) may not be appropriate. The effect of alcohol on motor vehicle fatality risk is almost entirely related to its effect on the driver while operating the vehicle. Alcohol can affect safety on the water in several ways, influencing both risk of ending up in the water or crashing, and on survival once there (Howland et al, 1993; McKnight et al, 1994; Smith et al, in press). Alcohol impairs balance and coordination, which can increase the risk of falling overboard whether a boat is underway or not. Impaired judgment resulting from an elevated BAC can also increase the likelihood of being in high-risk situations; and, unlike on the roadway, the operator cannot necessarily protect impaired occupants even in commercial boating or shipping. The effects of alcohol on the probability of survival once a person enters the water include an increased risk of hypothermia and a reduced ability to keep the head above water. Thus, a simple fall overboard can prove fatal. Our finding of a higher alcohol risk for boating than for driving is consistent with this compounding of risks.

There are a number of other important differences regarding alcohol use on the water versus the highway. On the highway, risk is almost entirely related to drinking by the driver, while on a boat, passengers can sustain injuries independent of the action of the operator. There are also differences in where drinking occurs. Typically alcohol-related motor vehicle crashes occur on route from a drinking location to another destination, with little drinking in the vehicle. There are also open container laws that restrict drinking in the vehicle. In contrast, drinking is an integral part of being on a boat for many people. In fact, some commercial boats are specifically designed for party activities involving alcohol.

Alcohol use has long been a part of recreational boating, with about 30-40% of boaters in most studies reporting drinking while boating (Logan et al, 1999; Howland et al, 1988, 1990, 1993, 1996; American Red Cross, 1991; Ciraulo et al, 2000; Glover et al, 1995). Many boaters believe that they can safely drink more when at anchor or tied up, and when they are passengers rather than operators (Howland, 1996). Current legislation focuses entirely on alcohol use by the boat operator while the boat is underway (prohibiting operation of a boat while intoxicated), as have many safety campaigns (Howland, 1993; NTSA, 1993). Some have even promoted the use of a designated driver when boating, with the implication that passengers can drink as much as they like as long as the operator remains sober. While these approaches initially appear attractive, they ignore the reality of what happens in most boating fatalities. Only a small proportion of deaths involve collisions. The majority of fatalities are due to drowning, often associated with falls overboard. Our findings clearly indicate that drinking passengers are at risk, independent of the sobriety of the operator. Passengers are free to place themselves in less safe positions in the boat where a fall overboard is more likely, for example, by sitting on the deck or leaning over the side, even in commercial boating or shipping.

The finding in our study and others, that many fatal accidents occur in unpowered or very low-powered boats, and that many others occur while boats are not in operation undermines the assumption that boat handling by drunken operators is a primary cause of boating fatalities. Unfortunately, since boating police rarely test surviving operators for alcohol use, it is not possible with current accident data to assess the role of impaired operators in increasing the risk of death for other boaters.

The shipping simulator studies strongly suggest that low BACs also increase risk in commercial shipping but more work is needed to confirm this. In addition our currently ongoing studies also suggest that occupational performance is impaired the day after intoxication, even when blood alcohol concentrations are at or near zero. If the residual effects of drinking such as hangovers can affect next-day performance, then current estimates of alcohol's contribution to injury could be greatly underestimated. Moreover, most of the public may be uninformed about these risks and public and corporate policy aimed at preventing alcohol-related injury may be less effective than intended, except in the case of aircraft operation where FAA, military, and commercial airline regulations acknowledge the residual effects of alcohol on pilot performance. Thus, the FAA requires a bottle to throttle period of 8 hours for pilots; the military requires 12 hours; and some commercial airlines require 24 hours. Our latest findings however suggest that even these restrictions may not be enough to prevent declines in performance (Howland et al, 2000 & 2001).

Policy Implications and Areas for Prevention Research

The implicit assumption of designated driver programs -- that a passenger can drink as long as the operator remains sober -- is dangerous for boaters and most likely for any activities on the water. All persons on a boat are at risk if they have been drinking, with increased risk evident at BAC levels as low as 10 mg/dl and increasing at higher alcohol concentrations. The risk associated with high BACs is, if anything, higher when the boat is not underway. These factors suggest that current efforts directed just at moving boat operators are likely to have less impact on alcohol-related boating fatalities than broader efforts to address drinking and safe boating by all occupants.

Approaches that have been shown to reduce other alcohol-related injuries have used a multifaceted approach to the development of interventions. These include increasing community awareness and mobilization around the problem, increasing the actual and perceived risk of apprehension for impaired operation and restricting availability and access to alcohol, including zoning ordinances and closing problem alcohol outlets (Holder et al, 2000). While some of these approaches are applicable to boaters, the independent risk of alcohol use by passengers, even on stationary boats, render some of the successful models from the highway less applicable. Certainly more efforts are needed to make boaters aware of the hazards of alcohol use, especially for passengers and when not underway, although these efforts on their own are not likely to be very effective at reducing the problem. Findings from community intervention studies (Holder et al, 2000) suggest that reducing the availability of alcohol can reduce injuries on the highway and other alcohol problems. However studies are needed to determine if these would be applicable to boaters. As examples of this approach, alcohol is prohibited at some lakes in North Carolina, and in some Canadian provinces alcohol use is restricted on the water, especially in small boats (e.g. those without sleeping quarters)(Pat, 2001). Also, since many fatalities involve alcohol consumed at bars and restaurants near the water, action taken against providers through alcohol control laws and server liability statutes could further reduce the toll. These approaches seem especially relevant in view of the evidence that the risk of dying increases even at quite low BACs.

Study Design Issues and Recommendations of Relevance to Other Studies

Many studies in the past have only used small sample sizes. Our boating study has the advantage of a fairly large sample with data on 4068 boaters and 330 boating fatalities across a wide variety of different boating environments. Few other studies have enough numbers to allow for examination of differential risks in important subgroups. We were also able to controll for many potentially confounding factors that affect risk such as boat type, age, gender, and time of day. Most studies in the past have not been able to do this which has been a significant limitation, especially when looking for the small increases of risk that are found at low BACs.

The case control study design has an important feature in all these studies in that it provides an adjustment for amount of boating activity, which is an important determinant of risk for most injuries, including aquatic injuries (Smith & Howland, 1999; Perneger & Smith, 1991). Another major strength of case-control studies such as ours was the use of direct BAC measurement for controls, which is an important component of most other studies of low BACs and actual injury risk in transportation, as against examining changes in performance. Changes seen in laboratory studies do not always translate into actual increases in real world situations. The ability to employ a BAC adjustment to account for the contribution of post-mortem alcohol production also allowed us to include several cases that otherwise would have been excluded from analysis, thus increasing the generalizability of our findings in the boating study. However decomposition and delayed body recovery times is not an issue for most studies on the highway.

Whereas many potentially confounding variables were taken into account in our boating study, we were unable to adjust for other variables that might affect risk such as the boater's swimming ability, the operator's boating skills and experience, water and weather conditions, personal flotation device (PFD) use, and the condition/seaworthiness of the boat. Although we controlled for boating exposure with the random selection of controls, it is possible that some groups, such as persons in boats who spent most of their time underway and made few stops, were underrepresented. We also did not have any data that would allow us to evaluate the effects of alcohol tolerance that was believed to be important in the "Grand Rapids Dip" (Hirst, 1985). We did not however observe any lower relative risks at low BACs in our boating study.

One relatively unique feature of our boating study was the use of a complex sampling design to ensure an adequate representation of controls from different times of day and from each waterway type used for recreational boating within distinct geographical regions of North Carolina and Maryland. One of the potential concerns with the recent studies of crash risk using the National Roadside Survey for controls and cases from FARS is that cases and controls may not come out of the same risk pool. More work is needed to examine this issue and I would like to see further discussion of this at the workshop.

Few studies consider the effect of refusal bias on BAC risk estimates. Adjustment for potential refusal bias in controls who did not give breath samples in our boating study (based on interviewer's impression of intoxication) was not found to significantly reduce the coefficients for the quadratic equation, despite the fact that controls who refused seemed to appear more intoxicated overall (based on interviewer's impression). Because subjective impressions of intoxication are known to be unreliable, we elected to present findings based on actual measurement observations in accordance with those few studies that have evaluated refusal bias (Moskowitz et al, 1999; Wells et al, 1997; Maul et al, 1984; Carlson et al, 1979). More work is needed to determine the effect of refusal bias, particularly in examining relative risks at low BACs.

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Alcohol and Boating: Comment on "Risk of Harm Associated with Low BACs: Lessons Outside the Highway"

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INTRODUCTION

In a single paper, Gordon Smith and his co-authors have provided solid information and thoughtful discussion on five separate topics. The paper:

- Reviews the literature on alcohol involvement in recreational boating deaths and injuries;
- Presents findings from the authors' recent case-control study of alcohol and recreational boating;
- Presents findings from the authors' recent simulator studies of the effects of alcohol on commercial maritime operations;
- Reviews studies that compare the risks associated with alcohol, speed, and fatigue; and
- Discusses the policy implications for efforts to reduce alcohol involvement in recreational boating.

These comments discuss the portions on recreational boating and their implications for alcohol-impaired driving on the highway.

WHAT'S KNOWN ABOUT ALCOHOL AND RECREATIONAL BOATING?

The paper reviews some 15 studies relating to alcohol and recreational boating. The most important points from these studies, collectively:

- Recreational boating is popular: over 43 million people in the United States participate annually.
- Alcohol is frequently involved: 30-40% of boaters report drinking while boating.
- Recreational boating produces more than 800 fatalities annually.
- About half of all fatalities had been drinking.
- Most occurred while the boat was at rest, only a few involved a crash.
- A typical victim drowned after falling overboard.
- Laws and safety campaigns directed at alcohol and boating concentrate on the boat operator and use methods similar to those employed for alcohol-impaired driving.

CASE-CONTROL STUDY

The authors' case-control study compared 221 case fatalities in Maryland and North Carolina from 1990 to 1998 with 3943 controls in the same states interviewed in 1997 and 1998. The fatalities corroborated and provided additional detail on the conclusions from the literature:

- Over half the fatalities were passengers.
- 55% had a positive BAC.

The case-control comparisons showed that fatality risk increases with BAC beginning at the lowest BAC. Fatality risk did not differ significantly between operators and passengers and also was not affected by gender, age, race, or boat size. At each positive BAC level, the relative risk of a boating fatality is higher than the relative risk of a traffic crash.

POLICY IMPLICATIONS

The authors conclude that the relative risks of alcohol in recreational boating may be higher than on the highway. They note important differences between the boating and highway environments: drinking usually occurs before driving while boaters drink while on the water; most alcohol effects on the highway operate through the driver while alcohol can affect operators or passengers alike on the water; most boating fatalities occurred while the boat was at rest while all traffic fatalities by definition involve a moving vehicle. They conclude that simply trying to adopt highway measures to boating, such as per se limits or "designated drivers", may not be appropriate.

These conclusions should be taken seriously. The evidence presented in the literature and the authors' case-control study shows clearly that alcohol's role in recreational boating has little relation to its role in driving on the highway. It's really more useful to consider recreational boating as recreation rather than transportation. Alcohol influences recreational boating fatalities much as it influences domestic violence incidents, homicides, and falls. The closest relation with highway safety is with alcohol-impaired pedestrians, not drunk drivers.

The policy implications are clear. As the authors conclude, laws and programs attempting to reduce "operating under the influence" address only a small portion of the problem and are extremely difficult to implement or enforce as well. Successful strategies must recognize that alcohol use is an integral part of recreational boating for many. My recommendations:

- Change the policy context from regulating operators to protecting passengers.
- Examine successful methods used in other situations where drinking is common, such as restaurants, bars, and at home.

In the long run, efforts to continue changing societal attitudes and norms regarding alcohol may be more effective than strategies directed specifically at recreational boating.

LESSONS FOR THE HIGHWAY

This is the only paper in the session "Risk of Harm Associated with Low BACs." The session was to address the question "What is the risk of crash involvement at low BACs?" The paper's data and conclusions really are more relevant to the opening sessions on the effects of low BACs on performance in non-driving situations. The paper's finding that fatality risk begins to increase at the lowest BAC corroborates similar findings from the laboratory reported in these sessions. The paper's simulator studies provide additional evidence.

But this all says nothing about the specific question of crash risk on the highway at low BACs. This is the critical link in the chain between laboratory data and policy actions. David Preusser's comments to the first three workshop papers examined this issue using induced exposure methods. He concluded that relative risk increases linearly, not exponentially, with BAC. In discussion, Herb Moskowitz noted that results from his replication of the Grand Rapids study also show increased risk at the lowest BACs. These comments lead to my research recommendation:

- Publish the Moskowitz study promptly; then review and synthesize all information on crash involvement risk as a function of BAC.

Implications of Research for Policy Concerning Low Blood Alcohol Concentration in Traffic Safety

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INTRODUCTION

Alcohol researchers within traffic safety have long known that drivers are impaired, on the average, after the first ingestion of alcohol. In terms of policy, the legally established Blood Alcohol Content (BAC) is a legal compromise as to when drivers will be presumed to be sufficiently legally impaired to be arrested (and convicted) for drinking and driving. While the United States has been a leader in many aspects of drinking and driving prevention, we have not been the world leader in lower BAC limits as a means for reducing alcohol-involved traffic crashes.

Papers presented at this workshop provide important empirical evidence that drivers have lower cognitive and performance skills as alcohol begins to be metabolized by the body and thus increased risk of crashes. Such evidence may, on the face of it, establish a mandate to lower the legal BAC level in each state since a clear policy implication is the potential to reduce alcohol impaired traffic crashes. However, as with most policy matters, things are not so simple.

This paper will summarize the empirical evidence as presented in the excellent papers in this workshop of particular policy relevance and then discuss the potential implications of such evidence amidst the more difficult and complex world of public policy.

EVIDENCE CONCERNING LOW BAC EFFECTS

The papers by Moskowitz (2001a), Vogel-Sprott (2001) and Burns and Fiorentiono (2001) provide a summary of laboratory research concerning the effect of blood alcohol concentration on motor skills and cognitive processing. Overall they found, what we have come to expect, which is that impairment begins when BAC ^{3} .01 or practically after the first drink. Such skills as cognition, perception, and visual function have been shown to be sensitive to alcohol in a wide variety of experimental studies. Additionally, simulator and road tests provide evidence of impairment in divided attention and vigilance tasks as well as drowsiness with low BAC levels. Researchers already knew that general relationship from the published research.

The laboratory studies further demonstrate significant differential affects on impairment that occur across gender, general drinking categories (based upon average quantity and frequency of alcohol consumption) and driving experience (which may be reflected in age differences). Burns and Fiorentiono (2001) summarize findings that demonstrate clear differences across driver characteristics. Of particular note is the relationship of driver performance to style of drinker, or as we in the alcohol research community have called this “tolerance” or learned compensation effect. In short, as the police found many years ago, heavy drinkers often learn to compensate for the effects of alcohol in order to avoid detection (and hopefully crash involvement). This, of course, suggests that it becomes practically possible for experienced drinkers to avoid detection because of their learned compensation. This has implications for drinking and driving enforcement since at lower BAC levels the traditional behavioral cues often used by police to spot impaired drivers may not be reliable in practice. The results of the driving simulator tests presented in this paper suggest that the percent changes in impairment between men and women will not assist in police recognition of alcohol impaired drivers. They do find, as expected, that younger drivers (under 21 years old) are clearly most impaired by alcohol at low BACs.

This theme is picked up in by Vogel-Sprott (2001) via the observation that one explanation for differences in impairment levels is that "alcohol triggers compensatory physiological reaction to restore homeostasis." Thus the implication of such findings is that BAC level alone is not a universal indicator of impairment or crash risk. Further Vogel-Sprott suggests as a prevention strategy that drinkers can be motivated to resist impairment (in spite of the natural affects of alcohol on the body). It just might be possible that drivers could be trained to overcome impairment caused by alcohol as a means to reduce crash risk in the way that general driving skills are taught to insure minimum driving performance. This observation and recommendation have very interesting policy implications that will be dealt with later.

Moving to epidemiology, there is further confirmation, though not as comprehensive, as the laboratory results. Moskowitz (2001b) in reviewing the nine controlled epidemiological studies of the relationship between crash and BAC found that only two studies dealt with the relationship of low BAC and crashes. The evidence in these studies also confirms the laboratory results that any departure from zero BAC increases crash probability. An almost identical conclusion is reached by Helander (2001). Both papers note that when the Grand Rapids data of crashes and BAC levels of drivers are corrected for methodological problems, the finding is clear that any amount of alcohol in the system of a driver increases the risk of crash.

Helander (2001) using data from FARS and a rather high BAC cutoff (> or < .10%) finds that the highest alcohol involvement occurs in drivers just above the legal drinking age. This matches the empirical evidence from general population studies which find that average consumption, particularly at drinking events, increases for young people (especially in males) under the age of 25, at which time there is an average drop in heavy drinking (although a small percentage continues to drink at high levels beyond 30 years old.) This paper points to the work of Fell using FARS data to note the strong association in alcohol crash involvement between BAC .01 to .09% for the youngest drivers, i.e., ages 16-19. This is also confirmed in California data that finds that younger driver arrests for DUI and/or involved in alcohol-involved traffic crashes are over represented at the lower end of the BAC spectrum (Helander, 2001).

Foss (2001) reviewed the results from five major roadside surveys concerning the potential prevalence of drivers with non-zero but low BAC (BAC< .050). The findings mirror crash results in that the 21-34-age range has the highest percentage of BAC positive drivers. He points out that about 10% of late night (10pm – 3am) weekend drivers are BAC positive but below .05%. His paper, along with others, presents the practical changes of adequate enforcement of low BAC limits and the difficulty with which drivers can accurately estimate their BAC.

ROLE OF RESEARCH IN ALCOHOL POLICY—IN GENERAL

Public policy strategies have been demonstrated over and over again to be especially potent in reducing alcohol problems. The role of research in U.S. alcohol policy is neither a great success nor a complete failure. Research is rarely the major factor in initiating discussion, consideration or debate, or policy enactment. At best, research serves as a reinforcer of politically held positions and at worst research is ignored. Actually the history of its role ranges over these extremes (Hawks, et al, 1993).

A policy is a rule, regulation, law, or organizational practice or priority that shapes the social, economic or geographic environment in order to prohibit a problem or risk behavior. For example, a law prohibiting the sale of tobacco or alcohol to people under a certain age, or the requirement that a sales tax be paid on a product in order to increase the retail product price, is a formal policy. Another example of policy is a decision by the local police to regularly enforce laws governing sales of alcohol or tobacco products. Such a policy decision (as opposed to a formal law) commits scarce law enforcement resources and thus likely reduces resources given to other crimes, e.g., burglary or speeding. Retailer compliance with underage alcohol laws is influenced by actual enforcement (Grube, 1997). Policies are generally designed to change the environment in ways that make behaviors less likely, either by raising costs or by reducing opportunities to engage in these activities. They may also reduce the likelihood that a behavior will result in a negative consequence such as a car crash.

Perhaps the best example of how research strengthens, supports, and aids alcohol policy is the passage of the national minimum drinking age (Wagenaar, 1983), where there was a clear interaction of research with the grass roots movements to support federal government incentives for states to pass a uniform 21-age-law. Mothers Against Drunk Driving (MADD), which originated as a support and action group for families of victims of drunk-driving crashes, increasingly drew public attention to the problem of drinking and driving. Media attention to this issue reinforced public concern and considerable action was taken.

Another example of research serving to support alcohol policy is the passage of the federally required alcohol container labeling. While no research on the effects of alcohol-warning labels existed (not surprising since there were no such labels), the research on the effects of cigarette warnings and non-prescription drug warnings supported the potential for such policy. In this context research served to support existing experiments or public deliberations concerning a new policy. Research was used to counter the claim that "no research exists to demonstrate the success (or potential harm) of a particular policy or its effectiveness."

Research helps stake out the areas of policy discussion. Research evidence may not be used to settle policy debate but to stimulate debate. Examples of research that appears to carry out this function are research on server liability, server training or responsible beverage service, and the research on the elimination of wine and spirits retail monopolies.

Research is also ignored in policy discussions. This is the domain that strikes "fear into the heart of every researcher," that no one pays any attention. The two good examples of research being ignored are econometric studies of the price elasticity of alcohol and the end of state restrictions on spirits sale by the drink in on-premise establishments. Perhaps the single largest collection of research evidence concerning potential alcohol prevention policy comes from price studies. None of the modest increases in federal and occasionally state alcohol excise taxes in the U.S. in recent years were based on the public health implications of tax policy. After North

Carolina ended its ban on liquor-by-the-drink, the two remaining states with similar bans, Oklahoma and Kansas, subsequently removed their bans. The research simply played no part in the public discussions, partly because the policy-relevant research from North Carolina was not yet available and partly because the changes were made in all three states because of economic considerations, not public health considerations. See Holder (1994).

Research can also be used against or to confuse policy discussion. While not a part of the prior discussion on changes in alcohol availability and access (since few changes have occurred), research concerning the effects of alcohol advertising or advertising laws has confused the policy discussion. The import of research in U.S. public alcohol policy concerning alcohol availability has been most often uncertain. Most changes in availability result from economic or social factors not a careful review of the research evidence. Of course, rarely are the results so unequivocal that studies showing conflicting results cannot be found. Unfortunately, the public and their elected officials are not able to evaluate the research methods employed in studies with different results. Most policy evaluations are not based on pre-planned controlled studies but on analysis of available longitudinal data and/or natural experiments. A good example of a government-sponsored effort to evaluate all available research on a policy topic was the U.S. Government Accounting Office review of minimum alcohol purchase age research prior to the national policy that effectively raised the minimum drinking age. This study, which was commissioned by the U.S. Congress, reviewed all published research, accounted for their differences in methods and quality, and reached a policy conclusion that there was clear evidence that higher minimum ages yielded reduced alcohol-involved traffic crashes for young people (U.S. General Accounting Office, 1987

There exist two major reasons why research has not played a routine role in the formulation of alcohol policy in the U.S. First, there is no provision in federal funding for research that can respond to policy initiatives. Research is usually initiated by researchers based upon their scientific interest. A minimum of one year in time is required to submit, have reviewed, and obtain funding (assuming everything goes well) for a policy-relevant research project. In most cases, the research funding will take much longer. As a result, research has its greatest effect when scientists anticipate and have already completed research, before policy debate begins. This has occurred in the U.S., e.g., minimum drinking age, server training, and server liability.

Secondly, there is little tradition in the U.S. for policymakers to consider research in their deliberations. Advocacy groups and lobbies with defined values and positions play a much greater role. Research has a role when it has been completed prior to policy debate and participants in the debate introduce it into the deliberations.

Research has its greatest effect when coupled with the pressure of “grass roots” movements. While the best example in the past decade has been minimum age, there are increasing potential examples. These include state efforts to raise alcohol excise taxes, which are (or will be) supported by public interest groups who want to reduce alcohol-involved injuries and deaths; mandated server training or server training as a protection against liability, supported by alcohol control authorities (as in the State of Oregon) and/or local alcohol establishments to reduce insurance costs; and future efforts to eliminate state alcohol monopolies, which are opposed by local organizations who treat alcoholics. In the final analysis, research to be effective needs “grass roots” support and such support for policy action is strengthened by research. See McCarthy and Wolfson (1996).

POLICY IMPLICATIONS OF EMPIRICAL EVIDENCE FOR TRAFFIC SAFETY POLICY

Nowhere have alcohol policy strategies been more employed and demonstrated to be effective than drinking and driving. In fact, in part due to the ready availability of traffic crash data and especially the FARS data, most national and many state and local public policy strategies for reducing alcohol problems have actually been tested using alcohol involved crashes as a major dependent variable (even if the main purpose of the policy was not simply to reduce crashes). Therefore, alcohol problem prevention using public policy and traffic safety have had a long and productive relationship. See summaries by: Edwards, et al. (1994), Wagenaar, et al. (2000), and Holder, et al. (2000).

While public policy has been typically defined in terms of legislation, law, and regulations, a broader definition of public policy is necessary in order to discuss the implications we are faced with in making effective use of the evidence concerning low BACs and alcohol impairment.

Thus policy implications involve both law and practice. That is, both the specific legal limit for BAC and the level of enforcement of any limit. I make this definition here because the policy implications for the U.S., based upon the empirical evidence AND the policy process itself, provide alternative ways to proceed.

One clear observation from many of the workshop papers is that drinking and driving enforcement in the U.S. at the local and state level is inconsistent at best. As a result the potential for a universal .08 law across states would be substantially limited with the inconsistent enforcement. As Moulden (2000) observed, there may be a low likelihood that the national goals of reducing alcohol-involved fatalities to no more than 11,000 by 2005 will be realized. Evidence for this skepticism is the modest reduction (approximately 9 percent) in such fatalities over the past five years or so. If and when the .08 limit is established in all states, inconsistent enforcement will most certainly reduce the potential of this lower limit to save lives. Therefore, is an even lower BAC level say .05 or even .02 reasonable or desirable?

On the face of things and from a public policy perspective of safety, such a lower limit seems axiomatically “yes.” Perhaps, all things being equal, that is a proper policy conclusion. However, as we learned from the effort to establish .08 as a standard across all states, lowering the BAC limit is neither politically easy nor simple to accomplish. Thus, a low BAC limit policy in the US is complicated by the evidence (as presented here), current practices of enforcement, and the position of the alcohol producing and distributing industry. Each of these deserve some discussion but for me, the real challenge is to consider, from a policy perspective, what our options are and which of these are most likely to yield the best returns. In order to sharpen the policy discussion, I have constructed a simple two-way table as shown below. This table presents a summary of alternatives concerning BAC limits and drinking and driving enforcement that deserve further discussion.

Possible Policy Approaches to BAC Limits and Enforcement: Examples of Potential Outcomes

DUI Enforcement	BAC at .08	BAC at .05 or lower
Maintain current levels and strategies	Modest effects on reducing alcohol-involved traffic crashes and fatalities. This is the status quo (or will be if and when all states set the .08 limit) even though there could still be political and legal efforts to allow states to set their own BAC limits without any national oversight or loss of funding.	Some effects on reducing alcohol-involved traffic crashes and fatalities. Likely to have higher effects than .08 with same level of enforcement. Political opposition from the alcohol industry would be high. Law enforcement support and implementation is likely to be inconsistent.
Consistent high levels of enforcement and regular publicity	Could produce greater reductions in alcohol-involved traffic crashes than possible with the .08 limit alone and the current level of enforcement. Any increased enforcement will both entail higher actual costs for officer time and equipment as well as resistance from some quarters of the enforcement community. Costs for increased and consistent enforcement could stimulate local and state government opposition. Frequent and visible enforcement could be opposed by citizen rights organizations.	Applied consistently, the low BAC limit with highly visible actual enforcement could produce the greatest return in crash reductions. Considerable resistance to a low BAC limit from alcohol industry could be expected. Alcohol retail establishments and their trade groups may well oppose wide-scale visible enforcement. Difficulty of enforcement and evidence of differences in impairment levels could be used to oppose the policy by law enforcement as well as by alcohol industry.

The implications for traffic safety above suggest potential political support and opposition, which are likely to occur in national, state, and local debates about drinking and driving. From a public safety perspective the potential of low BAC limits coupled with consistent, frequent, and highly visible and publicized enforcement is very likely to save lives. However, as we all know the public policy is rarely, if ever, based solely upon empirical evidence or such potentials. Many political issues surround any changes, no matter their public health and safety merit.

There are three major barriers that I can see, to achieving the lower bottom right cell of this table and these barriers appear in some form in all of the cells. First is research evidence itself. As noted above in discussions of general alcohol policy, research evidence before the fact is rarely unequivocal. We now have substantial research evidence that the minimum drinking age reduces traffic crashes for youth drivers as well as lowering youthful alcohol consumption, particularly high volume consumption. However, when the national debates were underway, there existed some evidence from individual states that had either lowered their minimum age or increased their minimum age AND there were some studies, which found NO effect. Therefore, a full and comprehensive research evaluation of either a state-wide or nation-wide low BAC legal limit can only be completed once the law has been on the books for some time. See Wagenaar and Toomey (2000).

As the evidence presented by some of the workshop papers demonstrates, there is considerable variation in level of impairment at low BAC levels across ages, genders and drinker categories. This is certainly understandable to researchers and consistent with many areas of policy effects. However, consider that this evidence could be used against any public policy for low BAC limits. For example, since there is wide variation across drivers (shown in such evidence) how can we establish a low limit that is fair and effective for all drivers? Obviously drivers, say heavy experienced drinkers, may be less dangerous than a light drinker due to his/her own inexperience with the impairing effects of alcohol. People will argue that the rights of regular and experienced alcohol consumers are being infringed upon due to the lack of experience of light drinkers with alcohol. This idea may seem comical but such arguments are already being used in other alcohol policy arenas. The licensed retail on premise establishments, which are often owned or managed by local citizens have already recognized that their best customers are special targets in DUI enforcement. Their trade groups, as was shown in the national opposition to the national .08 debates, will most certainly seek to use our own empirical evidence against these policies. The counter to this argument is that while the level of impairment is varied, there is a consistent finding that all drivers are impaired to some degree (some more than others) when BAC rises above zero.

An area where the role of research has been quite positive is the passage of zero tolerance laws including lower BAC driving limits for young drivers. The effects of such laws are summarized by Voas and Tippetts (2001). The success of early low BAC limits for young drivers certainly assisted the national effort to achieve zero tolerance laws as a national standard. The evidence presented in several of the workshop papers confirms again that younger drivers are more impaired at lower BAC levels than older drivers. Young people are less experienced as drivers and as drinkers. However, the policy achievement for Zero Tolerance is not so generalizable to the total driving population and low BAC limits. The U.S. has long been more willing to establish laws governing the young, both because of our concern for their health and their safety but also because they do not have the same political potency as the adult population. Zero tolerance laws are desirable additions to alcohol and public health policy, but we must be cautious about the political possibilities to easily extend these low BAC limits to the adult driving population.

The second area of concern is law enforcement. As we all know law enforcement at the state and local levels is generally under funded for the large number of tasks and responsibilities assigned. Most experience patrol officers know the problem of drinking and driving but they are also acutely aware of the practical and legal difficulties in enforcing the law. When the BAC limit is set much lower say .02 or even .05, the task of the officer might be easier or it could be more difficult. The low BAC limits can make the task of detecting and demonstrating impairment easier. That is, a driver cannot easily say, "Officer I have only had a couple of beers." Any evidence of prior drinking might increase the officer's desire and ability to check a driver more carefully. However, as Burns and Fiorentino (2001) observe, the ability of an officer to detect impairment at low BAC levels using visual or odor cues is limited without a breath-checking instrument. Low BAC levels could make convictions more possible. Some of the gray areas in the court processing of DUI cases might be removed.

One practical advantage of higher BAC limits is that a driver with a high BAC is obviously a serious traffic safety risk. The low BAC limits, regardless of research evidence, could also make enforcement and conviction difficult since the impairment levels are not as high as with say .08 or .10. This will most certainly be used in defending DUI cases. The sensitivity of breath equipment and the potential for breath testers to be confused by other sources of alcohol may also confound enforcement.

This is also a time to note the cost of increased enforcement and the demands for better equipment and training for officers to enforce low BAC levels. In many states, it is already difficult for officers, due to inadequate equipment, training, and police policy, to enforce low BAC levels for transport drivers and for young people. Therefore, for a low BAC limit for all ages to be most effective, actual enforcement must be consistent, highly visible, frequent, and widely publicized. Consistent and visible enforcement (most likely some form of Random or Comprehensive Breath Testing) requires operation policy by enforcement authorities to do so, additional funding for time, training, and equipment to pay for such enforcement, and public support for the police to undertake such levels of enforcement. As many controlled experiments in visible enforcement have shown, the success of such efforts clearly rides upon the foundation of actual enforcement and public awareness of such enforcement.

The news media play important roles in establishing public agendas on issues for both policy makers and the public. This is not necessarily telling people what to think but rather what to think about. News coverage can stimulate discussion about an issue and legitimize policy options. Recognition of this fact has led citizen groups and public health advocates to engage consciously in sustained action to achieve media news coverage on key alcohol policy issues. One effective means to accomplish this is through the local news media, which is often referred to as "media advocacy." Thus, local media news and feature coverage are often an important part of local prevention tactics. This could take the form of a major news event (Holder, 1994). In this way, the news media are not subject to a public relations campaign that seeks to shape the slant or approach, which the media gives an issue. A defined policy that can reduce high-risk drinking is thus a major requirement of media advocacy. A primary audience is the decision makers who can actually bring about desired policy changes at a local level, e.g., increase DUI enforcement. This may include elected officials such as city council members or county council members or supervisors, public agency representatives such as directors/heads of local police departments or school superintendents, or private business managers or directors, including owners and operators of licensed alcohol establishments (see Casswell, 2000).

Even if local decision makers do not support and are even uninterested in an issue, effective media advocacy can change local priorities if the decision maker recognizes the level of community importance assigned to a specific alcohol problem and the associated preventative policy. In short, the primary theoretical relationship is that community pressure affects decision maker behavior and this pressure is caused by clearly stated policy objectives, increased community awareness, and active community support of the policy objectives. In this case the use of media advocacy would be an essential strategy in increasing and sustaining public support for higher standards of DUI enforcement as well as their awareness of such enforcement (Holder and Treno, 1997).

Awareness with no increase in enforcement rapidly decays enforcement effectiveness and enforcement with no increase in public awareness has little real effect. See Voas, et al. (2001) concerning the essential effect of news attention to "Operation Safe Crossing" at the U.S.-Mexican border from Tijuana and San Diego where there was a 26% reduction in late night drinking drivers who crossed the border. The community trials project of the Prevention Research Center in Berkeley clearly confirmed the essential role of public support along with news attention to enforcement. Increased news coverage of DUI enforcement in the experimental communities compared to the comparison communities and a corresponding increase in the public's perception of personal risk of detection for drinking and driving and subsequent arrest by the police for Driving While Impaired (DWI) resulted in fewer BAC positive drivers on the road and a 10% reduction in alcohol-involved crashes. This increased coverage provided support for increased enforcement by the police (who need confirmation that what they are doing is supported by the community) and for increased perceived risk by the driving public. (Voas, Holder, and Gruenewald, 1998; Holder, et al., 2000).

The third type of barrier is the opposition of the alcohol industry and in some cases the citizen rights organizations. As was shown in the national debate concerning a national BAC level of .08, the alcohol production, distribution, and retail sales organizations are very likely to oppose a low BAC limit in the U.S., either at the state level or most certainly at the national level. This is not to paint the alcohol industry as the "bad guys" but rather to honestly acknowledge their political interests and their rather significant political potency. The alcohol industry faces one economic reality. That is, heavy drinking customers (often themselves dependent drinkers) are approximately 10% of the drinking population but they consume over 50% of the alcohol produced. These customers, on the average, are more likely than the "average" drinker to have higher BAC levels when drinking. Such customers are more likely than other drinkers to more often be at a level that would result in arrest while driving if low BAC levels are set. Therefore, from a simple marketing and profit strategy, anything that impedes or reduces the consumption of this heavy drinking group has tangible economic consequences for the alcohol industry. Recognition of this phenomenon is essential to any discussion of public policy alternatives.

Citizens' rights organizations have a somewhat different agenda, which seems to flow from a libertarian foundation, i.e., no government is the best government. From a public safety perspective this is a difficult standard since as we all know, left to their own devices the driving public will not necessarily make decisions about their drinking which lower crash risk. However, one of the barriers to adopting the consistent and visible standards of Random Breath Testing (RBT) or Compulsive Breath Testing (CBT) has in some cases been the opposition of citizen rights advocates who argue that mandatory testing without external evidence of impairment by a driver is an infringement on the privacy rights of citizens. Therefore, no matter the rather considerable evidence of the effectiveness of RBT or CBT in Australia and New Zealand, no U.S. state and few if any communities have employed RBT with sufficient consistency to achieve the types of effects which have been demonstrated in these countries.

Special note: There is one policy strategy concerning low BAC levels of impairment, which is worthy of further discussion. This was advanced by Vogel-Sprott (2001) who suggests that drinkers can be motivated to resist impairment (in spite of the natural affects of alcohol on the body) and that drivers could be trained to overcome impairment caused by alcohol as a means to reduce crash risk in the same way that general driving skills are taught to insure minimum driving performance. The field of alcohol problem prevention has often considered such suggestions concerning reducing alcohol-related harms via increased decision-making capacity, information levels, and skill building. One of the challenges to raising the minimum drinking age in the U.S. was the observation that young people needed to learn to drink and not to deny them the opportunity to acquire alcohol. Rather they should be enrolled in drink training (for example, in the home with parents) as a means to learn how to drink responsibility. Unfortunately, young people are already enrolled in such drinking training, i.e., social and peer groups at both the high school and college age levels. While there is a considerable wish, for example, among colleges to utilize social norms education as a means to reduce the pattern of heavy drinking by young people, the evidence does not support the optimism. In short, the previous efforts to "train" drinkers has had limited or sustained effects in actually reducing high risk, binge drinking. There is also a bit of contradiction in the strategy since heavy drinkers have the most experience with the effects of alcohol and, on the average, have more experience with overcoming the skill decay associated with too much drinking. Training less experienced drinkers to cope with impairment rides close to a public advocacy for risky drinking, since through training crash risk could be reduced. The risk of trauma associated with alcohol extends beyond driving and includes violence, falls, drowning, and burns. A drinker at a low BAC level is not only at risk for injury and even death even if they do not drive an automobile.

Further, such a suggestion (which has an interesting and rather intriguing possibility to reduce the risk level of less experienced drinkers if applied widely and effectively) has dangerous policy implications. Those who would oppose and do oppose low BAC limits and systematic enforcement, would (and could) join this advocacy for drinker training as an alternative to low BAC limits. In short, if drinkers can be trained to overcome the impairment effects of alcohol, then we would not need low BAC limits, could be the counter argument. This could strike at the basic foundation on which BAC limits rest.

CONCLUSIONS AND RECOMMENDATIONS

Any assessment of the policy implications of low BAC limits for traffic safety is at best a qualitative one. The cautions and barriers identified above are to establish an informed basis for considering such limits as a part of public policy. Despite the strength of the laboratory evidence about BAC impairment and the epidemiological evidence of crash risks at low BAC levels, this evidence alone will be insufficient to create a state or national policy of low BAC limits.

The major recommendations of this paper are based upon a general foundation that will support future possibilities for establishing low BAC limits for driving in the United States. They include:

1. Increase the threat (probability) of arrest and punishment for driving with a BAC >=.08.
2. Use media advocacy to increase public awareness of personal risk of detection as a result of this BAC, i.e., raise the driving public's perception of risk of detection.

3. Increase current drinking and driving enforcement in support of both 1 and 2 above. This recommendation is to increase the visibility, consistency, and extensiveness of current DUI enforcement in support of currently existing BAC limits. The true potential of a national limit of .08 will not be realized without such increased enforcement and the accompanying public awareness of increased enforcement. This alternative has both cost and political implications to be fully realized.
4. Build upon the current public support of Zero Tolerance as described in other papers, which suggest public acceptance of lower BAC levels for youth drivers and commercial drivers.
5. Train local police and prosecutors in order to increase risk of conviction.

To lower the BAC limit to .05 or .02 (for example) without an increase in DUI enforcement and public awareness, will achieve some positive benefit but at a considerable political cost (see above) for the actual change in legislation at the national and/or state levels.

The optimal policy alternative as suggested in the table is to establish a low BAC limit AND to increase actual enforcement and public awareness. This policy alternative has the greatest potential to save lives and reduce alcohol-involved crashes but is the alternative with the highest number of barriers to overcome. This does not mean that such an alternative should not be a destination for traffic safety, but there must be clear recognition of the rocky and difficult path down which we must travel to reach such a destination.

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Comment on “Implications of Research for Policy Concerning Low Blood Alcohol Concentration in Traffic Safety”

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Harold Holder nicely summarizes the workshop papers and provides an interesting discussion of the interplay between research and policy in the alcohol area. Noting that lower BAC limits would be justified as policy based on research indicating impairment and increased crash risk with any drinking, Holder offers for discussion four possible scenarios of lower BAC limits with varying levels of enforcement and publicity.

Of course, instituting lower BAC limits does not necessarily reduce the problem of alcohol-impaired driving. And as Holder notes, since research clarifying the effects of a policy cannot be done until the policy is at least partially implemented, and the research takes time to complete, the full impact of a policy may not be known until it is fully established, i.e., after the fact. Fortunately, many alcohol policies are instituted at the state level and thus phased in, and researchers can take advantage of the opportunities for natural experiments that arise from this process.

Holder refers several times to the minimum alcohol purchase age in his discussions of the intertwining of research and policy. I think that the path to this legislation also provides a good comparison — a contrast actually — with the path to 0.08. There were two paths involving minimum alcohol purchase age legislation. Before 1970, most states had laws prohibiting those less than 21 years old from purchasing alcoholic beverages. Ratification of the Twenty-sixth Amendment, which extended the right to vote to 18 year olds, was followed by lowered purchase ages in 29 states during the early 1970s. Research indicated that this legislation resulted in increased involvement of young drivers in crashes, and this was one of the factors that led states that had lowered their alcohol purchase ages to raise them, starting in 1976 and continuing into the 1980s.

Raising the alcohol purchase age was a contentious issue, not unlike 0.08, and this gave rise to all sorts of “research” studies in support of positions. There were studies showing positive effects, no effects, and even negative effects. But from the start, the well-designed studies showed substantial positive effects; the inferior studies were the ones that did not. This was later confirmed by the General Accounting Office review published in 1987 (General Accounting Office, 1987). My point is that in the case of alcohol purchase age legislation, science was ahead of policy, or at least in lock step with it.

The case for 0.08 is less clear-cut. The actual change from 0.10 to 0.08 is small, and reductions in alcohol impaired driving are contingent on affecting people with BACs outside this narrow range. As in the case of the alcohol purchase age, states have changed from 0.10 to 0.08 over time, allowing study, but for quite a while the research evidence was such that the effect of moving to 0.08 was too close to call. However, many of the safety organizations that usually base their positions on research findings were advocating 0.08 during this period. That is, policy was ahead of science. It is only recently that the effects of 0.08 are becoming clearer, and I don't believe yet that the evidence can be called definitive.

Of course, as Holder notes, a law's effectiveness is greatly determined by how well it is enforced and publicized, which in turn depends on its acceptability, and this will be a determining factor in the success of 0.08 in reducing alcohol-impaired driving.

Since we're now in the process of moving to 0.08 in the United States, the timing is not right for 0.05. Is 0.05 in the future? I've recently spent some time in Australia, where they drink more than we do in the United States, and they seem very accepting of 0.05. I expect that if we voted among ourselves whether we thought 0.05 should be implemented in the United States now or in the future, the vote would be split. Public acceptability would be an issue, in considering a BAC threshold where some people at least are minimally impaired. Police motivation to enforce would be questionable, and, as has been noted, their ability to enforce would be limited. We know that in sobriety checkpoints, a main though underused weapon against alcohol impaired driving, police do not detain most drivers with BACs of 0.05-0.08 or the majority of those with BACs in excess of 0.10 where signs of impairment are more often found (Wells et al., 1997). Police reluctance to use passive alcohol sensors, which can markedly improve their detection capabilities is well known. Convictions could be difficult to come by since the way our criminal justice system operates, convictions generally hinge on demonstrating impairment, despite per se laws.

Holder raises the issue of doing random breath testing as in Australia and here I disagree with his assessment. This isn't an issue of "opposition of citizen rights advocates who argue that mandatory testing without external evidence of impairment by a driver is an infringement of the privacy rights of citizens." It is a fundamental constitutional issue that isn't subject to state law. The U. S. Supreme Court decision held that the minimal stop occasioned by a sobriety checkpoint was reasonable given the state's interest in advancing highway safety. Breath testing is not a minimal stop. It is a full blown search and seizure, taking as it does, a sample of deep lung air, and no court could characterize it as other than a search and seizure. That means there must be either a warrant or probable cause to believe DUI has been committed before a breath test may be required.

This leads me to recommendations regarding BAC policies. First, we have a social movement in progress as more and more states move to 0.08, under the threat of federal penalties. This provides the opportunity to further clarify the effects of this change, an opportunity that should not be missed. Secondly, as Holder notes, the United States has not been a world leader in lower BAC limits, but we can and should carefully monitor the experience of other countries that have reduced the BAC threshold to 0.08, or 0.05, or even 0.02. Third, in an era where 1980s-style attention to the alcohol-impaired driving problem has waned, we need to encourage more vigorous enforcement of the BAC laws we presently have, e.g., changing zero tolerance laws and practices that inhibit enforcement (Ferguson et al., 2000), and greater use of sobriety checkpoints and passive alcohol sensors.

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Comment on “Implications of Research for Policy Concerning Low Blood Alcohol Concentration in Traffic Safety”

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Dr. Holder’s paper lays out very well the policy implication of the presentations made at this symposium. I would like to discuss some of these implications of research from a somewhat different perspective.

The research clearly shows that there is impairment and increased risk of crashes at all levels of BAC. The consistent evidence in this country as well as in others is that when the legal BAC is lowered a safety benefit results. The degree of that benefit depends on a number of factors, including the level of public education, the level of enforcement and the degree of publicity of that enforcement. However, even without increased enforcement, there is some benefit.

The commercial transportation industries provide a somewhat different example of the effects of lowered BACs.

In the 1970’s and 1980’s there were a number of high profile crashes and incidents that led to the call for prevention programs. It was cases like the Exxon Valdez, the Chase, MD AMTRAK collision, commercial pilots caught flying under the influence, and others that brought about public support for action. Studies by the DOT, Insurance Institute for Highway Safety, the National Transportation Safety Board and others showed significant alcohol and drug use by operators of commercial vehicles.

In the 1980’s the DOT began implementing prevention programs that called for no use of alcohol or drugs for workers in safety sensitive positions. These programs included clear policy statements against use, worker education programs and various types of drug and alcohol testing programs. There efforts were aided by the passage of the Omnibus Transportation Employee Testing Act of 1991, directing drug and alcohol testing for employees in safety sensitive functions. These programs have proven to be very successful in all the transportation modes. For example, a low rate of alcohol use by interstate truck and bus drivers, coupled with industry promotion of alcohol-free driving, led the FHWA to reduce the random alcohol testing rate for 1998 to 10 percent from 25 percent. The alcohol testing violation rate was just 0.18 percent of all drivers tested in 1996. Similar results were achieved in the other modes of transportation.

It is now accepted that there should be no use of alcohol when operating a commercial vehicle. This applies in all modes of transportation - rail, rapid transit, marine, aviation and highway. It also applies to all types of flying - not just commercial aviation. The rules and regulations that cover these industries, for various legal and other reasons, have established the legal limit at .04 percent or lower. But the bottom line is that any alcohol use by these operators is incompatible with safe operation.

How can what was accomplished in the commercial area be translated into strategies that would encompass all drivers? First, it is pretty clear that the public accepted the fact that operating a commercial vehicle while under the influence of any alcohol was a threat to public safety. If the public believes it is a threat for professional trained and experienced drivers, how much of a stretch would it be to convince the public that driving by anyone while under the influence of any alcohol is a similar threat to public safety? While incidents in commercial transportation gain headlines, it is, of course, ordinary passenger vehicles that are involved in the vast majority of deaths and injuries. It may be possible to convince the general public that drivers of passenger vehicles also pose a threat to public safety if they drive with any alcohol in their systems.

An argument against moving the legal BAC for all drivers even lower can be made that enforcement of the low BAC limits could take resources from enforcement activities aimed at the higher risk high BAC drivers and from other police enforcement priorities. I would agree that we should ensure that our enforcement efforts are aimed at the areas in which there can be the largest safety payoff and certainly should not neglect the highest risk drivers, but it is possible to encompass all impaired drivers in our enforcement efforts. The more widespread use of sobriety checkpoints in particular can enforce lower BAC limits without sacrificing enforcement at higher levels. The use of passive sensors would be particularly effective in this regard. But in any event, it appears that establishing a lower BAC and making the public aware of the new limit will have some benefit, even without increased enforcement.

If we look at history, we might predict that the US will eventually follow the rest of the industrialized world and implement a .05 percent BAC. The research discussed at this workshop certainly supports such a move. In a perfect world we might expect to set a legal standard that acknowledges the impairing effects of any alcohol in all driving – not just commercial transportation. This is, of course far from a perfect world. Will we ever see a Swedish type .02 percent BAC in this country? The opponents of any reduction in BAC level have a lot of money to give to those who must make those decisions. In any event lowering the legal limit below .08 percent will not happen by itself.

The way to overcome the influence of the opponents is to gain wide public support. Among other things, that will require a greater degree of advocacy on the part of the research community than we have seen in the past. Researchers should become more active as advocates for the findings of their research. Researchers and scientists are very well respected members of the community and their voices carry a lot of weight. They need to utilize the prestige they have gained to help influence public policy. Many of you may feel uncomfortable in the role of advocating what your research has shown, but I would suggest that you have an obligation to take the next step. That is especially the case if the research is publicly funded. Some researchers, including a number who are here today, already are advocates for their findings, but many more need to get involved.

Low BAC Policies: Results and Mechanisms

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BACKGROUND

The significance of alcohol impairment to involvement in highway crashes was recognized early in the last century, but it was only in the last third of the century that chemical tests and BAC levels became an important factor in DWI (driving while intoxicated) laws and law enforcement. The first scientific report on alcohol-related crashes occurred in 1904 (U.S. DOT, 1968), but it was not until the 1940s that alcohol tests began to come into use in the prosecution of impaired drivers (AMA, 1976). Moreover, although other industrialized nations began adopting per se laws in the first half of the century (e.g., Norway in 1936), the United States did not begin until the last half of the century. In 1939, Indiana became the first state to provide chemical testing for alcohol It was not until the 1960s, however, that Nebraska led the way by enacting a per se law; still, by 1970, only 5 states had such laws (AMA, 1976). Further, despite recent focus on lowering BAC limits from .10 to .08, chemical tests play a smaller role in the prosecution of DWI cases in the criminal justice system in the United States than in most other industrialized nations.

Among industrialized nations, three basic DWI enforcement procedures predominate: behavior-based enforcement, chemistry-based enforcement, and mixed systems. Each system features two elements in the arrest process: (1) selecting a vehicle from the traffic flow and (2) examining the driver to determine the level of impairment, if any (Table 1).

TABLE 1 Use of BAC test for the three main types of enforcement

	Selecting Vehicle from Traffic Flow	**Examining Driver**
Behavior based enforcement	Stopping for individualized erratic driving	No breath test – must observe and document impaired behavior
Chemistry based enforcement	Random stopping	Breath test all drivers
Mixed (British Road Safety Act)	Stopping for (1) traffic offences, (2) crash, (3) officer suspicions	Breath test all drivers stopped for cause

The *behavior-based system*, the first to be used, relies on the judgment of police officers. Officers patrolling the highways are trained to look for signs of erratic driving that might indicate an impaired driver. Observation of erratic behavior by a driver gives the officer probable cause to stop the vehicle. The officer then interviews the driver and requires him or her perform sobriety tests, the results of which could provide enough evidence to male an arrest for DWI. In contrast, the *chemistry-based system* relies on scientific measurement of the blood alcohol concentration (BAC) and is done at random. The Australian random-testing programs best exemplify this system: vehicles are selected randomly from the traffic flow and drivers are required to take a breath test at the roadside. Arrests are made based on the test's outcome. In *mixed systems*, drivers are not stopped at random, but all those displaying specifically defined behaviors such as being involved in a crash are required to take a BAC test.

The chemistry-based system was developed principally in Sweden and is used in other Scandinavian countries. It is most aggressively used, however, in Australia where the best evidence for its effectiveness has been produced (Homel, McKay, & Henstridge, 1995).

The mixed system is best exemplified by the British Road Safety Act of 1967, which was so well evaluated by Ross (1973). This law gives police the power to demand a breath test from a driver under three circumstances: (1) the officer observed behavior that indicated intoxication, (2) the driver committed a moving traffic violation, or (3) the driver was involved in a crash. Because the British Road Safety Act featured the use of portable devices to test motorists in the field, which is typical of enforcement in Sweden and Norway, Ross characterized such policies as Scandinavian type DWI laws. However, Britain did not allow random stopping that was a major feature of enforcement in Sweden, so this approach is best characterized as a mixed system because it combines both behavior and chemistry-based enforcement.

In part, because of the provisions of the 4th Amendment to the Constitution regarding search and seizures (stopping a vehicle is a seizure; breath testing is a search), DWI enforcement in the United States follows the behavioral model. Vehicles are stopped when an officer observes erratic or illegal driving, and arrests are based on an officer's observation of the driver's performance on the sobriety tests. Although 37 states report conducting sobriety checkpoints, a system for randomly stopping vehicles, these occur so infrequently as to be relatively unimportant in the overall enforcement system. Further, even though many police departments equip their officers with handheld breath-test devices, these are mostly used after the officer has already decided, based on the sobriety test, to arrest the suspected driver. Today, officers are better trained to detect impairment and use more systematic observational procedures. In essence, even though there are some exceptions, police in the United States are enforcing drunk-driving laws much as was done in the early 20th century—by observation of driver behavior. This relatively limited role of chemical testing in the enforcement of DWI laws needs to be kept in mind in considering the potential impact of lowering legal BAC limits.

FIVE NATIONAL PROGRAMS LOWER/LIMIT DRIVERS' BACS

The 51 jurisdictions (50 states and the District of Columbia) in the United States offer numerous and varied laws covering BAC specifications. The research attention and financial incentives provided by the federal government have motivated states to adopt legislation, producing a wave of action across the country as each new law is popularized. During the last 30 years, there have been five such waves related to reducing the legal BAC limit.

1. The movement from .15 to .10 BAC;
2. The establishment of the minimum legal drinking age at 21 years;
3. The establishment of the .04 limit for commercial drivers;
4. The enactment of zero tolerance laws for drivers younger than 21 years; and
5. The enactment of .08 laws.

During this period, there have also been two waves of lawmaking—per se laws and administrative license revocation (ALR) laws—that, though not directly lowering the legal BAC limit, have been important to the effectiveness of such laws.

History of Efforts to Reduce Legal BAC Limits

As early as 1939, the House of Delegates of the American Medical Association (AMA) adopted a resolution specifying that "All persons show a definite loss of clearness of intellect" at BACs higher than .15 (AMA, 1976, page 145). By 1945, a three-level definition of the relationship of BAC to impairment had been adopted by the AMA in their proposed model DWI law. BACs of .15 or higher were presumptive evidence of impairment; BACs between .05 and .15 were valid evidence of impairment to be considered with other relevant behavioral evidence but did not lead to a presumption; and a BAC lower than .05 provided a presumption that the individual was not guilty of DWI. The presumption that a driver with a BAC higher than .15 was impaired shifted the burden of proof to the defendant to demonstrate that this was not the case. Such a presumption is not as strong as a per se law that makes such a BAC the offense itself. This is the starting point for U.S. efforts to reduce the legal BAC limit.

Reducing the BAC Limit from .15 to .10: In 1960, both the AMA and the Committee on Alcohol and Drugs of the National Safety Council adopted resolutions recommending that the BAC level of .15 be reduced to .10. In 1962, this reduction was reflected in the Uniform Vehicle Code (UVC) as shown in Table 2. By 1968, eight states still had not adopted chemical test laws, and only 11 of the 42 states with such laws had set the presumptive level at .10. (Note, however, that Utah already had an .08 law, and New York had an .05 law for drivers younger than 21 years.) Weakening the potential impact of reducing the BAC level from .15 to .10 was the fact that 21 states did not have implied consent laws with which to motivate offenders to submit to a chemical test. New York was the first state with such a law, and the implied consent provision did not appear in the UVC until 1962 (AMA, 1976). In addition to the limited opportunity for impact of the piecemeal implementation of the lower limits without the supporting effects of implied consent and ALR laws, researchers did not have relatively sophisticated crash record systems, such as the Fatality Analysis Reporting System (FARS), that are available to investigators today. As a result, there were no adequate evaluations of the impact of this trend to lowering the legal BAC limit.

TABLE 2 Section 11-902 of the 1962 Uniform Vehicle Regarding BAC Limits

Sec. 11-902-Persons under the influence of intoxicating liquor

(a) It is unlawful and punishable as provided in section11-902.2 for any person who is under the influence of intoxicating liquor to drive or be in actual physical control of any vehicle within this State.

(b) Upon the trail of any civil or criminal action or proceeding arising out of acts alleged to have been committed by any person while driving or in actual physical control of a vehicle while under the influence of intoxicating liquor, the amount of alcohol in the person's blood at the time alleged as shown by chemical analysis of the person's blood urine, breath, or other bodily substance shall give rise to the following presumptions:

1. If there was at that time 0.05 percent or less by weight of alcohol in the person's blood, it shall be presumed that the person was not under the influence of intoxicating liquor.
2. If there was at that time in excess of 0.05 percent but less than 0.10 percent by weight of alcohol in the person's blood, such fact shall not give rise to any presumption that the person was or was not under the influence of intoxicating liquor, but such fact may be considered with other competent evidence in determining whether the person was under the influence of intoxicating liquor.
3. If there was at that time 0.10 percent or more by weight of alcohol in the person's blood, it shall

be presumed that the person was under the influence of intoxicating liquor.

Passage of minimum legal drinking age (MLDA) laws: Triggered by the Vietnam War, the voting age was reduced to 18, which was soon followed by laws to lower the drinking age in 29 states (Toomey, Rosenfeld, & Wagenaar, 1996). These laws provided public health researchers with an opportunity to study their effect on traffic injuries of young drivers aged 18 to 20 years. The increase in such injuries resulted in a reversal of the trend to lower the drinking age and, by 1988 with pressure from the federal government, all states had adopted age 21 drinking laws. These MLDA laws—lowering the drinking age, then raising the drinking age—provided researchers with an unusual natural experiment, culminating in this legislation being the most studied and perhaps best-documented in the history of highway safety. In 1993, Wagenaar reviewed 29 studies on the increase in the MLDA: 20 showed decreases in underage traffic injuries, 3 showed no change, and 6 were inconclusive. In a recent nationwide study, Voas, Tippetts, and Fell (2000b) found a 19% decrease in the proportion of underage drinking drivers in fatal crashes associated with the MLDA law. As of 1999, the National Highway Traffic Safety Administration (NHTSA) has estimated that MLDA laws have prevented 20,000 fatalities.

The .04 BAC limit for commercial vehicles: The Commercial Motor Vehicle Act (Title XII of Public Law 99-570, Oct. 27, 1986) called for a National Academy of Sciences study of the appropriate legal BAC limit for commercial drivers. They anticipated the study result by providing that the legal limit would be set at .04 if the NHTSA did not complete rulemaking within 2 years. The Transportation Research Board (TRB) established an expert panel to review the available information on the behavioral effects of alcohol and on deterrence and the effect of law enforcement. In 1987, the panel recommended the .04 BAC limit and proposed an additional zero limit, enforced by removing the commercial rig from the road for a period of 24 hours (TRB, 1987). In addition, the expert panel suggested several enforcement procedures for detecting low BAC drivers, including the use of both preliminary breath sensors and passive breath sensors.

Based on information from U.S. and foreign evaluations of the enforcement of lower legal BACs in the late 1980s, the panel estimated that compared to the 80 to 140 lives saved with a commercial limit of .10, a zero limit would have saved 130 to 250 lives but would have increased enforcement costs from $30 to $54 million. However, the panel noted that “federal sanctions for noncompliance ... [by the states in passing the requisite legislation] ... will not become applicable until 1993 [6 years after the legislation]. In short, the reform will become effective haltingly rather than in one dramatic nationwide change. This ... will complicate the research problem of evaluating [the effectiveness of the new laws].” (TRB, 1987, page 109) This appears to have been the case because this reviewer is not aware of a quantitative evaluation of the commercial driver .04 BAC limit.

Zero tolerance for drivers younger than 21 years: Implementation by the states of the age 21 MLDA law opened the way for establishing a zero BAC limit for drivers younger than 21 years. In 1983, Maine became the first state to adopt such a law. Evaluations of the impact of zero tolerance laws in states adopting this provision early on (Hingson, Heeren, & Morelock, 1986; Hingson, Howland, Heeren, & Winter, 1991; Hingson, Heeren, & Winter, 1994 & in-press; Blomberg, 1992) indicated that it was effective in reducing alcohol-related fatal crashes in underage drivers. Hingson and his coworkers estimated that, if all states passed zero tolerance laws, an estimated 300 lives could be saved each year. This led Congress to enact legislation requiring all states to implement zero tolerance legislation or face a reduction in their highway construction funding. With this stimulus, all states enacted zero laws by 1998. A study by Voas, Tippetts, and Fell (2000) of all 50 states during a 16-year period reported a 24% reduction in the proportion of underage drinking drivers in fatal crashes.

Reducing the BAC limit to .08: Perhaps the most contentious alcohol safety issue in the last three decades has been the proposal to reduce the legal BAC limit from .10 to .08. The hospitality industry, claiming that the limit would criminalize social drinkers, mounted significant opposition to this proposal (American Beverage Institute, 1999). In addition, there was considerable concern among some investigators as to whether an .08 limit would have a significant impact on the high BAC drivers who make up the largest portion of the drinking drivers in fatal crashes (Simpson, Mayhew, & Beirness, 1996). To date, there have been 10 published studies on the effect of the .08 law. Two of these studies, one covering California (Rogers, 1995) and the other covering North Carolina (Foss, Stewart and Reinfurt, 1998), found little or no evidence for the effectiveness of the .08 law. The remaining eight studies have all reported positive results (Hingson Heeren, & Winter, 1996, 2000; Hingson, Heeren, Levenson, Jamanka, & Voas, 2001 in-press; NHTSA 1991, 1999; Johnson & Fell, 1995; Voas et al., 2000b; Voas, Taylor, Kelley Baker, & Tippetts, 2000a). The most comprehensive of these studies (Hingson et al., 2000; Voas et al., 2000b) found similar treatment effects of approximately an 8% reduction in alcohol-related crashes. This led to the estimate that, had all states implemented .08 laws, 300 lives would have been saved.

The political interest in the .08 issue led to a review of studies by the GAO, which became available in 1999. The GAO report concluded, “While indications are that .08 BAC laws in combination with other drunk-driving laws as well as sustained public education and information efforts and strong enforcement can be effective, the evidence does not conclusively establish that .08 BAC laws by themselves result in reductions in the number and severity of crashes involving alcohol.” (GAO, 1999, p. 22) However, this statement could be made about any piece of alcohol legislation including the .10 BAC limit it was replacing. Further, no law can operate alone without the support of all the other elements of a complete impaired driving system; therefore, this conclusion was relatively meaningless. Despite this negative report, the Congress enacted a law requiring all states to pass .08 laws or face the loss of highway construction funds. As of June 2001, 27 states have passed such laws.

The five waves of legislation briefly summarized above all relate to lowering the legal BAC. They were not the only or even the most important impaired driving legislation enacted by the states in the last third of the 20th century. Legislation defining BAC limits as illegal per se and ALR and implied consent laws are critical to the effective functioning of the impaired driving control system and probably as important, or even more important, than lower legal BAC laws. Also not covered above is the lower BAC law that may create the next wave of state BAC legislation: zero tolerance for convicted DWI violators. Hingson, Heeren, and Winter (1998) studied the law enacted by the state of Maine in 1988 making it an offense for a driver with a conviction for DWI to have a BAC of .05 or higher. They found that DWI offender recidivism declined by 25% following enactment of that law. Maine later reduced the limit for offenders to .02 BAC. Other states are considering this legislation. If it continues to be effective, it will probably be enacted in most states during the next few years.

Measuring the Overall Effectiveness of BAC Limits

The best method for determining the effect of lowering the legal BAC is to study individual states as they implement a lower limit. However, one limitation on that procedure is that it does not reveal the long-term effect of the law. If lowering the legal BAC is effective, then the gradual reduction in legal BAC limits through the last three decades of the 20th century should be expected to result in a national reduction in the number of drinking drivers in crashes over time. The FARS, which is a census of all fatal crashes that occur in the United States, includes a record of the BAC of drivers involved in such crashes. Where this information is missing, imputed BAC values are provided. This allows a separate analysis of the number of drinking (BAC>.00) drivers compared to nondrinking (BAC=.00)drivers in fatal crashes. If the lowering of BAC limits has had an impact on alcohol-related fatal crashes, then the number of drinking drivers in fatal crashes should be reduced relative to zero BAC drivers.

Figure 1 contrasts the trend in the number of drinking to the number of nondrinking male drivers in the young adult 21- to 34-age group, which has the highest involvement in alcohol-related crashes. As can be seen, between 1982 and 1999 the number of nondrinking male drivers in fatal crashes decreased by about 15%. In contrast, the number of male drinking driver in fatal crashes decreased by 50%.

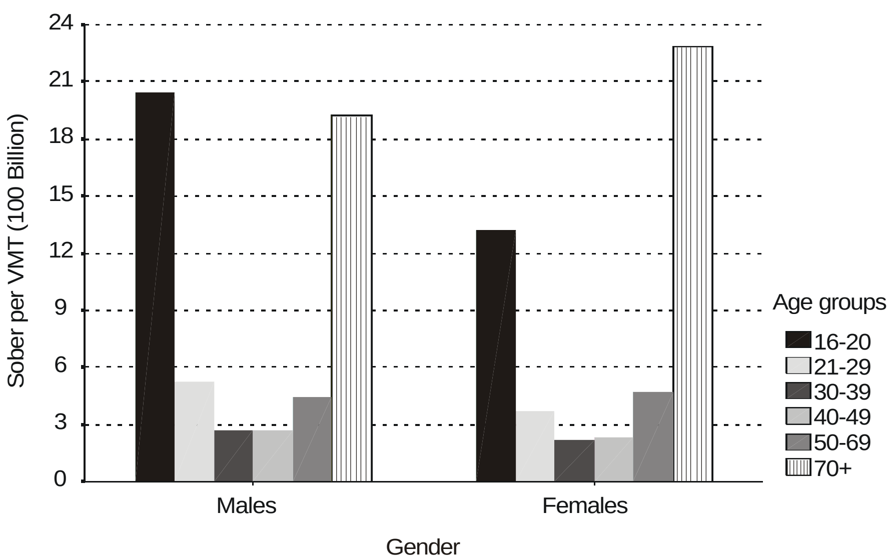

FIGURE 1 Sober (BAC=0) drivers as a function of reported annual vehicle miles as a function of age and gender

The number of female drivers in fatal crashes is much smaller than males, but the number of sober drivers in such crashes increased by 14% between 1982 and 1999 while the number of women drivers who were drinking decrease by a third (see Figure 2). These trends support the conclusion that the general lowering together with the overall strengthening of alcohol laws by the passage of such measures as implied consent and ALR has resulted in a reduction in alcohol-related fatal crashes. Figure 3 illustrates how the percentage of drivers in fatal crashes who were alcohol-involved decreased for every level of BAC.

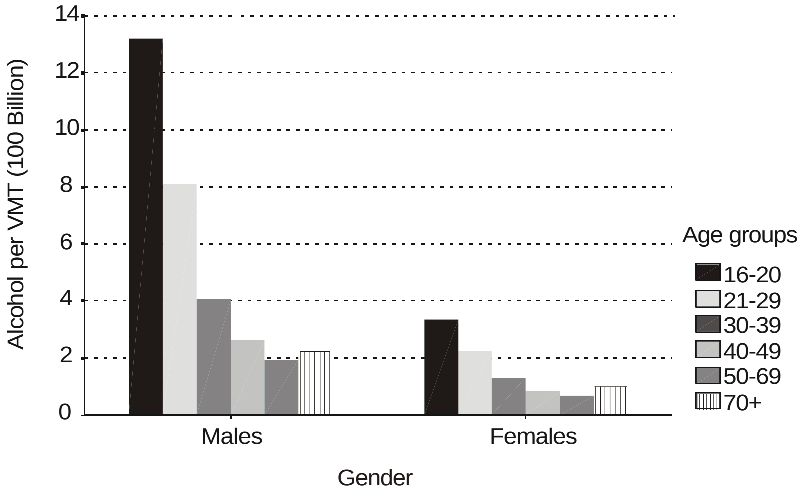

FIGURE 2 Drinking drivers (BAC>.00) as a function of reported annual vehicle miles as a function of age and gender

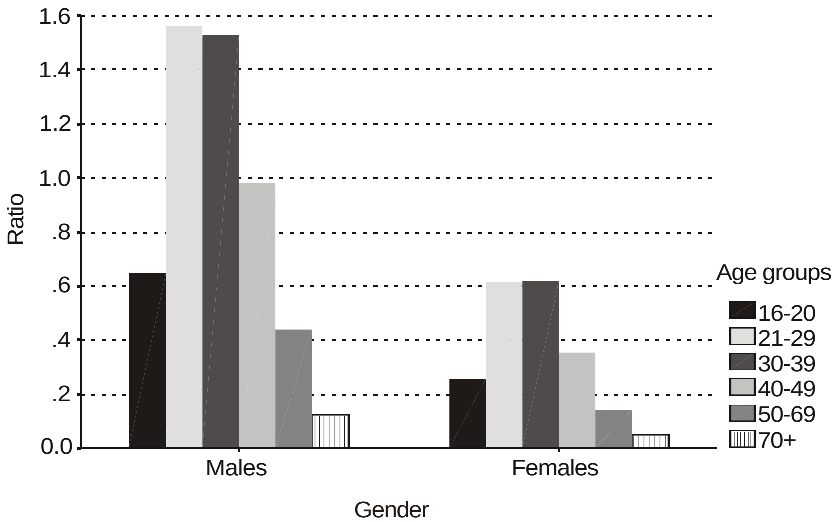

FIGURE 3 Odds that a driver in a fatal crash will have been drinking as a function of age and gender

Two of the most important low BAC laws were the MLDA and the zero tolerance for drivers younger than 21. That these two pieces of legislation were effective is suggested by information shown in Figures 4 and 5. From 1982 to 1999, the number of male nondrinking drivers younger than 21 remained the same, and the number of nondrinking female drivers younger than 21 increased by 75%. In contrast, the number of male underage drinking drivers decreased by 40%, and the number of underage drinking drivers decreased by 59%.

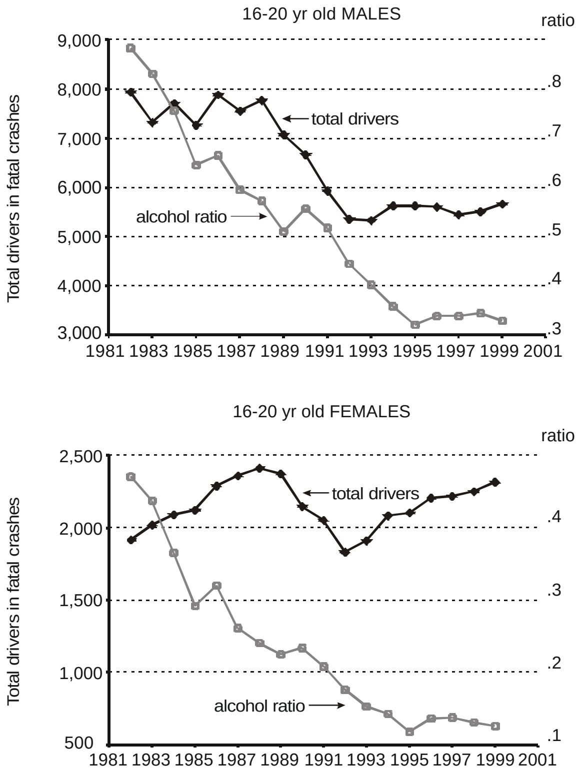

FIGURE 4 Total male and total female drivers age 16-20 in fatal crashes and the odds that a crash involved driver will have been drinking, 1982 to 1999

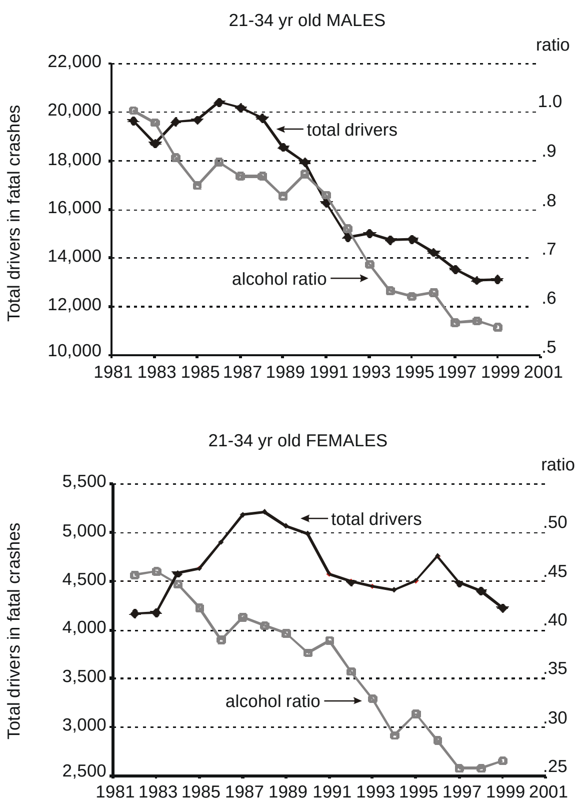

FIGURE 5 Total male and female drivers age 21-34 in fatal crashes and the odds that a driver in a fatal crash will have been drinking from 1982 to 1999 in the U.S.

The data in Figure 6 also indicates the effectiveness of the MLDA law. This figure shows a gradual rise in the involvement of drinking drivers in fatal crashes from age 16 to 20, then a substantial rise at age 21, followed by the leveling of the growth rate during the early years of adulthood. It is not possible to tell whether the rise in the percentage of drinking drivers in fatal crashes reflects a maturation process or reflects the greater ease of access to alcohol as the youths approach age 21.

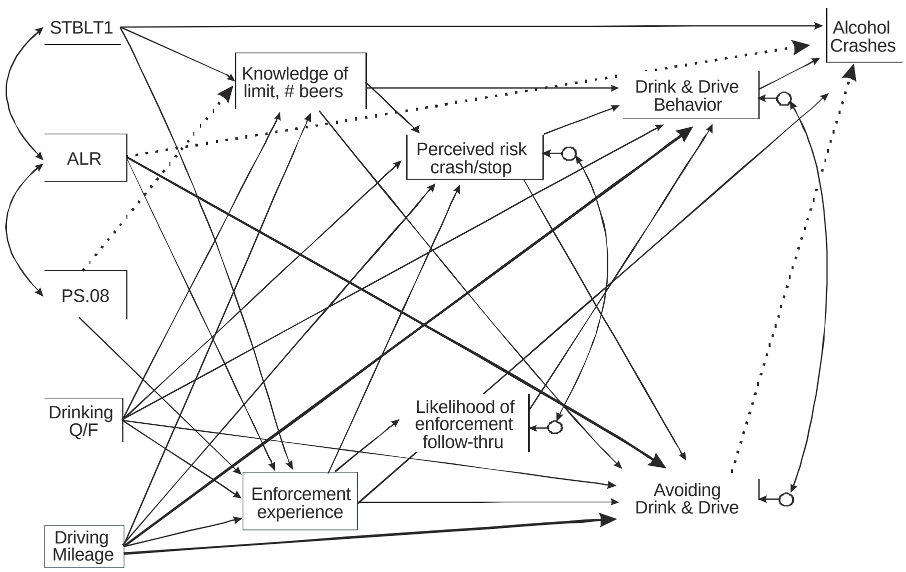

FIGURE 6 Cross-Validated Deterrence Model

RECOMMENDATIONS FOR FUTURE ACTION

The major area for action in the future lies, not so much in passing new legislation, but in publicizing and enforcing existing legislation. Three areas deserving increased attention are public education, motivating police to enforce underage drinking and drinking-and-driving laws, and implementing a chemistry-based enforcement system. These three areas are discussed in the following paragraphs.

Public Education

Public education programs directed at reducing alcohol-related crashes fall into two broad types: public service announcements and media advocacy.

At the national or state level, public service announcements or, in some cases, paid media advertisements have been used to promote safety policies. There is proven technology for producing effective advertisements based on the media's experience with commercial advertising. The strength of this procedure is that it produces high-quality material that can be widely distributed nationwide. It has limited effectiveness at the community level, however, because public service spots are generally given low priority time slots unless considerable effort is made by local activists.

A more effective method at the community level is media advocacy, which is a process for generating "earned" media through community efforts to create news events that attract press coverage. The strength of this procedure is that it dramatizes the problem within the community. It focuses on community leaders and co-opts them into supporting the local safety effort. Whereas public service announcements are targeted only at the problem behavior (e.g., underage drinking), media advocacy primarily targets local government officials and activists whose support is required to promote action programs by organizations such as the police or the schools. There is a need to increase the training and resources available to community leaders for media advocacy in order to make progress in motivating police to give DWI and underage enforcement higher priority.

Motivating Police to Enforce Underage Drinking and Drinking-and-Driving Laws

The best available evidence indicates that, even though the MLDA and the zero tolerance laws have made a difference (see above), they are generally poorly enforced (Wagenaar & Wolfson, 1995; Ferguson, Fields, & Voas, 2000). One significant barrier to enforcement appears to be the general belief among police officers that underage drinking and drinking-and-driving are not a major problem and the community does not support active enforcement of those laws. This partially reflects a public ambivalence, which has been illustrated by the recent coverage of the illicit drinking of the President's daughters. Although legislation to protect children in general receives consistent support at the state and federal level, when the issue is personalized at the community level, underage drinking and drinking-and-driving are more likely to be excused as a right of passage over which too much fuss is being made. The police encounter this ambivalence and conclude that it supports their own view of underage alcohol experimentation.

Recent evidence suggests, however, that the early onset of drinking has important consequences for adult involvement in drinking-and-driving offenses and crashes (Hingson, et al., 2001 in-press). There is also evidence that it is also associated with changes in brain function. Dramatization of this type of information needs to be used at the community level to change the local view of the significance of limiting the availability of alcohol to youth and enforcing the zero tolerance law. Significantly greater support for underage drinking enforcement is required to: (1) increase the priority given to the problem by police departments; (2) support funding for the preliminary and passive sensors needed to enforce underage laws effectively, and (3) encourage the development of underage service facilities for youths apprehended with alcohol so that police officers do not have to spend a great deal of time babysitting offenders while they locate their parents. Finally, legislation or local ordinances may be necessary to establish the authority of police to apprehend underage drinkers for possession based on breath alcohol rather than requiring that the offender have a container in his or her possession, as is currently the practice in most places.

Implementing a Chemistry-Based Enforcement System

Random testing in the Australian manner is not possible under our constitution, but the Supreme Court's acceptance of sobriety checkpoints and the availability of passive sensors provides the opportunity to mimic their random-testing system if police departments could be persuaded to do so. Currently, departments believe that mounting checkpoints is too expensive (Fell, Ferguson, Williams, & Fields, 2001 under review). They believe that checkpoints require a large number of officers and do not result in very many arrests. Some states do not permit sobriety checkpoints and, in most of those that do, the police department relies on federal funding to pay the costs of special operations such as checkpoints.

To overcome this limitation, departments need to be persuaded to mount small checkpoint operations as a routine part of their DWI enforcement activities. One method by which this could be accomplished would be to set up a procedure in which brief (1- to 2-hour) checkpoint operations would be regularly implemented at selected sites on weekend evenings, staffed by no more than four or five officers. These officers would spend the majority of their time on weekend evenings on their normal selective enforcement patrols but would assemble at the checkpoint at a predetermined hour. After conducting the checkpoint for an hour or two, they would return to their normal patrol work. Strong community support would be needed to ensure that the police department would have the equipment (e.g., sensors and van for breath testing and holding offenders) required for this type of operation. With such support, officers might be more motivated to take part in a checkpoint as a break from their more routine patrol activities.

As noted, what remains to be accomplished in alcohol safety falls principally in the area of operations rather than legislation. We may find that passing laws was the easy part!

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Comment on "Low BAC Policies: Results and Mechanisms"

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INTRODUCTION

The questions we are being asked to address are as follows: W hat have been the results of lowering BAC limits for the general driving public? For specific populations? What are the likely mechanisms by which these results have been achieved?

One of the advantages about being a discussant is that it provides the opportunity not only to put one's own perspective on the data, but also to be somewhat more speculative. I will try to avoid the temptation to stray too far from the science in so doing.

In his paper Voas discusses the effectiveness in reducing alcohol-related crashes (to the extent that it is known) of various laws in the United States that have lowered BAC thresholds for some or all of the population. Included was the move from 0.15 to 0.10 percent in the United States (see Voas for a discussion of this issue), Minimum Purchase Age Laws, an 0.04 threshold for commercial drivers, zero tolerance laws for young drivers, and the reduction from 0.10 to 0.08 percent in some states. The Voas paper does not address the effectiveness of reductions in the BAC threshold in other countries such as Canada, Sweden, and Australia. Nor does he draw from the experiences of our neighbor to the north who have not followed the same path when it comes to underage drinking. I will take a moment to discuss what is known from these experiences because I think these changes, and the overall pattern of drinking and driving and alcohol-related crashes in other countries can provide some insights about the mechanisms by which any reductions seen in alcohol-related crashes might be occurring. Although policy is not the purview of this paper, these changes also have important implications for where we go in the future.

YOUNG DRIVERS

I would like to examine the issues related to drinking and driving among young drivers in more depth because it is clear we have been doing a better job of reducing alcohol-related fatalities among this group than among other age groups. Given the inevitable aging of the population, it is perplexing that when these same youth reach 21 some of the gains we have made begin to wane.

There is very strong evidence that Minimum Legal Drinking Age Laws (MLDAs) in the United States have been effective in reducing alcohol-related crashes. A number of different studies have consistently estimated about a 10-20 percent reduction in crashes/fatal crashes as the result of the passage of these laws (GAO, 1987; Williams et al, 1983; Wagenaar, 1993; Voas et al, 2000). Zero tolerance laws also have been effective in reducing alcohol-related fatal crashes in underage drivers. A number of studies have estimated about a 10-25 percent reduction in such crashes (Hingson et al, 1986; Hingson et al., 1991, Hingson et al., 1994; Blomberg, 1992).

The question is, what are the mechanisms by which these reductions have occurred? Survey data indicate that Minimum purchase age laws have affected youth drinking as well as drinking and driving as measured by fatal crash rates (O'Malley and Wagenaar, 1991). However, as Hedlund et al (2001) point out, among high school seniors decreases in self-reported drinking throughout the 1980s were not entirely due to these laws because reductions also occurred in states that already had age 21 laws in place during the same period. Survey data from the Monitoring the Future Study and other studies of college students and young adults (see Hedlund et al, 2001 for a summary), suggest that the decrease in drinking among high school seniors has also occurred into the early 20s. There is also clear evidence of an even larger reduction in reports of drinking and driving among high school and college students. There is still substantial drinking that occurs in underage youth, but according to Hedlund et al. there is evidence young people under the age of 21 are separating their drinking from their drinking and driving more than those 21 and older. During 1982-1998 the magnitude of the reductions in reported drinking and driving and fatal crashes involving youth were similar, whereas measures of reported drinking during the same period did not decline as much.

This viewpoint is mirrored in a recent study by Wagenaar et al (2001) who looked at the effects of zero tolerance laws on drinking and drinking and driving among high school seniors using data from the Monitoring the Future study. According to Wagenaar, the lower BAC thresholds did not appear to affect the overall amount of drinking among underage youth but they did find about a 20 percent reduction in drinking and driving before and after passage of zero tolerance laws in the United States.

Why did these changes come about? This is a more difficult question to answer because neither MLDA laws not zero tolerance laws are widely enforced (Ferguson et al, 2000; Wolfson et al, 1995). Neither is knowledge of zero tolerance laws widespread according to surveys conducted in selected states (Ferguson et al, 2001; Hingson et al., 1991; Voas et al., 1998). Underage youth still have fairly ready access to alcohol and for a variety of reasons very few young drivers are cited for zero tolerance violations. Enforcing zero tolerance laws is difficult in practice. Drivers with low BACs will not exhibit the same kinds of driving cues that intoxicated drivers do and police officers have not changed impaired driver enforcement practices to target this population. Drivers with low BACs therefore may only come to the attention of police officers if they commit some other infraction. Furthermore, the laws in some states make it very difficult to enforce in practice (Ferguson et al, 2000). Another puzzling factor is that, in Canada where 18 and 19 year-olds are permitted to purchase alcohol, there has been a similar downward trend in alcohol-related fatal crashes involving teenage drivers (Hedlund et al, 2001). Surveys in Ontario also show large reductions in self-reports of drinking and drinking and driving (Smart et al., 1994). Furthermore, zero tolerance laws were not typically enacted until 1994-1999, after the reduction in alcohol-related crashes had occurred. All of this suggests that laws and their enforcement alone were not responsible for the reductions in the United States. Hedlund et al. (2001) point to educational and motivational programs in place during the last 20 years as a possible, but unconfirmed source of these changes. Somehow we have managed to convince a substantial proportion of teenagers to separate their drinking from their driving.

So what happens when drivers turn 21? According to data presented by Voas, the proportion of drinking to non-drinking drivers in fatal crashes is much higher than that of underage drivers. Furthermore, the reductions in alcohol-related fatal crashes and those involving illegal levels of alcohol have not declined by as much in this age group (IIHS, 2000). Results of observational surveys also confirm higher proportions of drinking drivers in this age group. Foss, based on a number of different surveys across the United States and Canada, finds far higher percentages of 21-34 year-olds are driving with low BACs compared with underage drivers. Data from the 1996 National Breath Survey indicates the proportion of drivers with BACs of 0.05 and 0.10 percent and above was much higher among drivers 21-34 than among younger drivers (Voas et al., 1997).

Once young people turn 21 there is a realization that they are now able to drink some amount of alcohol and still legally drive. When you ask most people how many drinks it takes to be over the legal limit they are likely to say 2 or 3 (Ferguson et al., 2000; Jones and Boyle, 1996), but when asked how many drinks it would take to affect driving or make them an unsafe driver this number is often larger – closer to 4 or 5 (Caetano et al., 2000; Ferguson et al., 2000). Clearly from crash and survey data many more in this age group are drinking in excess of the legal threshold compared with drivers of other ages. There is also evidence that drinking drivers have no real perception of what their own BACs might be. Among drivers interviewed at the roadside in Canada, 83 percent of drivers with BACs of between 0.08 and 0.15, thought they were not over the limit (Mayhew, 1995). For those in excess of a 0.15 percent BAC the percentage was around 60.

Why this disconnection? Beirness (1984, 1987) has argued that drinkers are extremely poor at estimating their BACs and/or the extent of their impairment. Errors such as these can lead people to make inappropriate decisions about whether they are safe to drive. Once young people reach the age of 21 if they begin to drive on occasion after drinking too much they will quickly discover that can do so without fear of a DWI conviction. Do they assume that this is because they are safe to drive or do they do it in full knowledge that they are disobeying the law? I would argue that it is some of both. That most people have no idea what their BAC is after drinking so they make a judgment based on how they feel. Survey data, if it can be believed, would suggest that most people who drive with illegal amounts of alcohol in their blood are reaching the conclusion that they are not impaired. Furthermore, there is likely a poor understanding of the metabolic effects of alcohol. How many people realize that once you have reached a high BAC it is a very slow process to eliminate alcohol from the body? Someone who has reached a BAC of 0.15 could take as long as 3-7 hours to be below the legal threshold of 0.08 (assuming a rate of 0.01-0.02 percent an hour elimination). Furthermore, there is evidence that once someone has reached a peak BAC and is in the elimination phase (the descending limb) they are even more likely to underestimate their BAC (Martin et al., 1991).

THE EFFECT OF LOW BAC POLICIES

There has been a prolonged debate in the U.S. about the effects of a reduction in the BAC threshold from 0.10 to 0.08. Several recent studies that have reviewed the literature have also reached mixed conclusions. A study undertaken by the Centers for Disease Control concluded that on average crash deaths dropped about 7 percent after 0.08 laws were adopted (Shults et al., 2001). Mann et al. (2001) came to a slightly different conclusion, that although findings were generally positive it was too soon to tell definitively. Studies undertaken in other countries that have reduced their thresholds from 0.08 to 0.05 percent and 0.05 to 0.02 percent (Sweden, Australia) have reported similar reductions (e.g., Henstridge et al., 1997; McLean and Kloeden, 1992; Ross and Klette, 1995). Although there is still some question about the methodological rigor of some of these studies, it seems reasonable to claim that reductions in the legal threshold could have a small effect on drinking and driving (see also Mann et al., 2001). These changes in the law typically have not been accompanied by heavy enforcement. Programs in the United States and Australia show that much bigger gains can be made when such changes are accompanied by a convincing show of enforcement. Random breath testing in Australia and widespread and frequent checkpoint programs in the U.S. can shown reductions in alcohol-related crashes of from 20 –48 percent (Henstridge et al., 1997; Lacey et al., 1999).

It is by now axiomatic that enforcement accompanied by publicity is the most effective means to reduce drinking and driving and alcohol-related crashes. No matter what the BAC threshold, people need to be convinced that there will be swift and sure penalties if they exceed it. As Ross took pains to point out, people will continue to drink and in many cases driving is a perceived necessity to get home particularly in countries where drinking establishments are not in close proximity to home. Presumably most people who go out to drink do not start out with the assumption that they will be getting too intoxicated to drive home so there comes a point in the evening when they have to make a decision about whether to get in their car. Subjective impressions of impairment as well as likelihood of arrest if you make the wrong decision both play a role in the ultimate outcome. It is tempting to suggest that we need to do a better job of getting the public well educated about the relationship between drinking and BAC, that is in their appreciation of the link between subjective perceptions of intoxication and actual BAC. There is a danger however in education. If many people currently believe they are over the limit after 2 or 3 drinks, educating them that they actually could drink more may be counterproductive. Furthermore this would change nothing if those who drink and drive routinely do not fear they will be apprehended for DWI if they are over the limit. In other words, we need to give them an incentive to care. The perceived threat of a DWI is the way to engender the concern regardless of the BAC threshold in place.

One final point. The lower the BAC threshold, the greater difficulty there will be in enforcing it. As Foss points out the likelihood of detection of a high BAC, even once a driver is stopped is very low. Furthermore, in the United States as Bob Voas points out, despite per se laws in almost every state, the gold standard for arrest and conviction of DWI is a combination of behavioral and chemical testing. A lower threshold than 0.08 percent would be a real challenge for the enforcement paradigm in use today. Australia has the perfect solution, random breath testing, but this is not going to work in the United States because it would not be acceptable under the Constitution. Wide use of passive sensors could help to detect drinking drivers in the first place, but it will be much tougher to achieve an enforcement paradigm where the results of chemical testing will be sufficient evidence to support a conviction.

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Comments on "Low BAC Policies: Results and Mechanisms"

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Dr. Voas and Tippets have provided an excellent historic overview of research regarding raising the minimum legal drinking age to 21, and legislation establishing legal blood alcohol limits for adult drivers and zero tolerance laws for drivers under 21. There are some additional studies not cited in their paper that provide further support their main observations and conclusions.

DRINKING AGE LAWS

Alex Wagenaar and Tracy Toomi have recently reviewed the literature on minimum legal drinking age laws for an NIAAA panel on college drinking. They sought to identify all published studies on the topic from 1960-1999. They searched:

- NIAAA's ETOH database 1960-1999
- Medline 1966-1999
- Current contents 1994-1999
- Social Science Abstracts 1983-1999

Forty seven studies with 66 alcohol consumption measures were identified. Of the 66 analyses, 56% reported an inverse relation. As the drinking age increased, drinking decreased and vice versa. Thirty nine percent of the analyses were reported to be statistically significant. Only 3 analyses (6%) of the total found the opposite relation.

Fifty seven studies assessed the effects of drinking age changes on car crashes. Ninety eight analyses were performed. Sixty percent found an inverse relation. Forty eight percent were reported to be statistically significant. Only 1 analysis 1% found a positive relation.

This is the most comprehensive review of the drinking age literature I have seen and it is in press in the Journal of Studies on Alcohol. It provides further evidence of the beneficial effects of raising the drinking age.

ZERO TOLERANCE

Wagenaar also just published an analysis of zero tolerance laws in the American Journal of Public Health. He examined data from the Monitoring the Future Study from 1984-1998. That study surveys over 17,000 high school students annually at 112 public and 23 private schools with a typical response rate of 85%.

When he compared student responses in the 30 states that adopted zero tolerance laws before and after enactment to national trends, he found no change in vehicle miles traveled or overall drinking after zero tolerance laws passed. He did report a post law 19% decline in driving after drinking in zero tolerance law states and a 23% decline in driving after 5+ drinks.

These survey results on driving after drinking were remarkably consistent with findings of the first multi state study of zero tolerance laws. Hingson, Hereen and Winter (1994 Public Health Reports) reported a 20% decline in the proportion of fatal crashes that were single vehicle at night in the first eight states to adopt zero tolerance laws relative to eight nearby states without such laws. These declines were identified in crashes involving drivers under 21 targeted by the laws. Much smaller declines were seen single vehicle night fatal crashes involving adult drivers and there were no differences between groups of states.

Of note, as in studies of .08% laws, lowering legal blood alcohol limits affected driving after any drinking and after drinking heavily.

.08% LAWS

Thomas Dee has just completed analysis based on data from the Fatality Analysis Reporting System from 1982-1998. Combining FARS, and state population dada, total weekend, weekday, nighttime and daytime traffic fatality rates were generated by state and year. He entered into a regression analysis whether the state had illegal per se at .08%, at .10%, administrative license revocation, dram shop statutes or case law, mandatory jail for first time DUI offense, a zero tolerance law, primary or secondary safety belt laws, a 65 MPH speed limit, a 70+ mph speed limit, vehicle miles traveled, state unemployment rates and personal income per capita in each state.

He found the .08% per se laws were associated with an 8.6% decline in weekend traffic fatalities, a 5.8% decline in weekday fatalities, a 6.5% reduction in nighttime fatalities and a 6.2% reduction in daytime fatalities. The .08% per se laws were associated with an overall fatality decline of 7.2%. The reductions were greatest among young drivers 14% among 18-20 year olds, 9.7% among 21-24 year olds and 6.7% among persons age 25 and older. These results were published in J. of Policy and Analysis 20(1) 131-148, 2001.

An interesting question is why are there reductions in alcohol related fatal crash after .08% law not only among drivers with blood alcohol levels close to the new limit but also those with high blood alcohol levels.

In 1994, Massachusetts passed a .08% administrative license revocation limit law. It is not a criminal per se law, but it was a lowering of the states presumptive level for driving while intoxicated from .10% to .08%.

Statewide random digit dial surveys conducted in 1993 before the law and after the law revealed a significant post law increase in the proportion of respondents who believed it very likely drunk drivers would be stopped by the police 11% to 24%, charged 52% to 63%, if charged, then convicted 34% to 47%, and have their license suspended before a trial 47% to 71% . Among persons who drank at least 10 drinks on an occasion in the past month the proportion increased who thought drunk drivers would be stopped by the police 9% to 31%, charged 65% to 77%, convicted 53% to 63%, and have their license suspended before a trial 52% to 68%.

Among all drivers the proportion who thought they could consume 4+ drinks and drive safely declined from 24 % to 15%, and the proportion who thought they could drink 4+ and drive legally declined from 16% to 9%. Among the heavy drinking group, there was little pre and post law change in the proportions who thought they could drink 4+ and drive safely. But there was a significant decline in the proportions who thought they could drink 4+ and drive legally 34% to 20%. The proportions of these heavy drinkers who reported drinking after 4+ drinks declined significantly from 39% to 29%. Among all drivers, those proportions declined from 9% before to

4% after the law. Time series analyses comparing Massachusetts to Connecticut 4 years before and 4 years after the law found a 13% greater post law decline in the proportion of Massachusetts drivers in fatal crashes with BAC's of .01% and 17% greater decline with BAC's of .10% +. Similar differences appeared when comparing Massachusetts to the other bordering states with .10% laws Rhode Island and New York.

When limits are lowered, even heavy drinkers seem to become aware of the change and accompanying publicity creates a sense of greater police and court drunk driving enforcement even among heavy drinkers.

After legal blood alcohol limits are lowered, there appear to be shifts among drivers including heavy drinkers in beliefs that it takes fewer drinks to reach the legal limit. Further, of note, even though the numbers of drunk driving arrests and convictions per year actually declined in Massachusetts after the law was implemented, the publicity that accompanied passage of the law and its implementation created perceptions even among heavy drinkers that drivers who exceeded the new blood alcohol limits would be stopped by the police, charged, convicted and punished.

IMPLEMENTATION

Dr. Voas and Tippetts conclude that education and enforcement are vital to the optimal life saving potential of lower legal blood alcohol limits.

This point in crucially important. Recent data from Dr. Henry Wechsler's 1999 College Alcohol Study reinforce problems in implementation of zero tolerance laws. In 1999 after all states adopted zero tolerance laws for drivers under 21 he surveyed 5,776 college students under age 21 at a random sample at 119 four year colleges nationwide. Thirty one percent erroneously believed they could consume 2 or more drinks and drive legally. Of those who thought they could drink 2 or more and drive legally 33% reported driving after drinking in the previous months compared to 20% who believed it illegal to drive after drinking. Seventeen percent who thought they could drive legally after 2 or more drinks drove after 5+ in the past month, twice the proportion of those who thought it illegal to drive after drinking.

Clearly education about the new limits backed up by publicized enforcement is crucial to their optimal success.

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- Doug Beirness and Kathy Stewart, who co-chaired the workshop. Kathy Stewart also provided a background section on the workshop for this Circular and a summary of papers and key points.
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- A planning group of Rob Foss, Jim Hedlund, Herb Moskowitz, and Allan Williams, who provided Doug Beirness and Kathy Stewart with initial guidance on the workshop.
- Special thanks to authors of background papers and discussion papers, which provided the framework for the workshop.

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APPENDIX A

Workshop Schedule

Transportation Research Board Midyear Meeting and Workshop
Committee on Alcohol, Other Drugs, and Transportation
Woods Hole, Massachusetts
July 23-24, 2001

EFFECTS OF LOW BLOOD ALCOHOL CONCENTRATIONS ON DRIVING PERFORMANCE AND CRASH RISK

Monday, July 23

7:30–8:30 a.m.	Breakfast
8:30–9:00 a.m.	Introduction to workshop *Allan Williams, Doug Beirness, Kathy Stewart*
9:00–9:30 a.m.	Experimental evidence I: laboratory studies of the effects of low BACs on performance *Herb Moskowitz*
9:30–10:00 a.m.	Experimental evidence II: studies of the effects of low BACs on driving performance *Marcelline Burns*
10:00–10:30 a.m.	Factors that enhance or mitigate the effects of low BACs *Muriel Vogel-Sprott*
10:30–11:00 a.m.	Break
11:00–11:30 a.m.	Discussants *David Preusser, Hans Laurell*
11:30–12:30 p.m.	General discussion of the experimental evidence
12:30–1:30 p.m.	Lunch
1:30–2:00 p.m.	Epidemiology part I: prevalence of drivers and drinkers with low BACs *Rob Foss*
2:00–2:45 p.m.	Epidemiology part II: crashes at low BACs *Cliff Helander, Herb Moskowitz*
2:45–3:15 p.m.	Break
3:15–3:45 p.m.	Discussants *Ruth Shults, Jim Fell*
3:45–5:00 p.m.	General discussion of epidemiology
5:00 p.m.	Reception and clambake

Tuesday, July 24

7:30–8:30 a.m.	Breakfast
8:30–9:00 a.m.	Risk of harm associated with low BACs *Gordon Smith*

9:00–9:30 a.m.	Discussants *Jim Hedlund, Richard Compton, Jean Shope*
9:30–10:00 a.m.	Low BAC policies: results and mechanisms *Bob Voas*
10:00–10:30 a.m.	Break
10:30–11:00 a.m.	Discussants *Sue Ferguson, Ralph Hingson*
11:00–12:00 p.m.	General discussion
12:00–1:00 p.m.	Lunch
1:00–1:30 p.m.	Implications of research for policy *Harold Holder*
1:30–2:00 p.m.	Discussants *Allan Williams, Barry Sweedler*
2:00–3:00 p.m.	General discussion
3:00 p.m.	Closing remarks

Sponsors

Centers for Disease Control
International Council on Alcohol, Drugs and Traffic Safety
National Highway Traffic Safety Administration
National Institute on Alcohol Abuse and Alcoholism
Transport Canada

APPENDIX B

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