

Submitted to: Substance Abuse Treatment, Prevention and Policy
<https://substanceabusepolicy.biomedcentral.com/>

A 'Hands on' Public Service Program to Help People Stay Sober and Safer on the Roadway

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Abstract

Background. Despite the existence of many different “Don’t drink and drive” programs and campaigns over the past 30 years, alcohol intoxication has continued to account for approximately one quarter to one third of all traffic crashes and crash-related deaths in the United States. The present study describes a new ‘hands on’ evidence-based approach involving real alcohol-intoxicated subjects using a virtual reality (VR) driving ‘game’ to educate the public more effectively about the dangers of drunk driving.

Method. A single demonstration subject ‘drove’ a VR-based portable driving simulator on multiple occasions before (Pre) and at 30 minute intervals for up to six hours after either vehicle (no alcohol), 2, 4 or 6 ‘drinks’ (3, 6, or 9 ounces of 80 proof vodka). The defensive driving task was a choice reaction crash avoidance steering maneuver in which the driver’s task was to determine which way to turn to avoid a crash and then aggressively steer away to avoid a crash. The primary dependent variable was the latency to initiate an avoidance steering response. BAC determinations (estimations) were conducted immediately prior to driving tests using BAC Track portable breathalyzers.

Results. Control drives (Pre-Treatment and Vehicle treatment) were characterized by an approximately 300-320 msec reaction time to initiate a crash avoidance. Alcohol increased crash-avoidance reaction time. Peak BAC values were 35, 78 and 120 mg/dl for 2,4 and 6 drinks, respectively; the decline in BAC was comparable and linear for all three treatments. There was a strong correlation ($r=0.85$) between pre-drive BAC level and reaction time across all of the alcohol-related drives. There was a significant increase in crash avoidance reaction time when the BAC was 50-79 mg/dl, which is below the legally-defined BAC limit (80 mg/dl) currently used in most states in the US.

Conclusions. These results demonstrate (1) this VR-based driving simulator task could be a useful ‘hands on’ tool for providing public service demonstrations regarding the hazards of drinking and driving and (2) a BAC concentration of 50 mg/dl represents a reasonable evidence-based cut-off for alcohol-impaired driving.

Key Words: alcohol, driving, driving simulator, drunk driving, impaired driving, road safety, drunk driving prevention, alcohol legal limit

Introduction

Drunk driving continues to be a significant cause of highway crashes and deaths. If there is any good news with respect to drunk driving, it is that there has been a significant decline in drunk driving-related deaths over the past 40 years or so. In the early early 1980s, nearly 45-50% of crash-related fatalities involved a driver with a BAC > 0.08%, whereas today that figure has been cut significantly, with approximately 30% of the crash-related fatalities involving drivers with a BAC > 0.08% (NHTSA 2018; Injury Facts, 2020). Several factors likely contributed to this decline. Legislative changes like the National Drinking Age Act of 1984 (APIS, 1984) and the National 0.08% BAC Cut-Off Act (Department of Transportation, 2000) have contributed significantly, as have the use of breathalyzer-dependent ignition lock-out devices (NHTSA, 2015; CDC, 2016) and sobriety checkpoints in states where they are allowed (CDC, 2015; Fell et al, 2004; Beck, 2009). In addition, advocacy/awareness groups such as Mothers Against Drunk Driving (madd.org), Students Against Destructive Decisions (sadd.org) and Designated Driver campaigns (Winstein, 2011) have likely had a significant positive effect. Many public service announcements, like “Friends don’t let friends drive drunk”, “Be sober or get pulled over”, have likely had an impact as well (Media Smarts, 2011). Finally, improvements in car and road conditions have probably contributed.

Despite the positive effects of these various initiatives to reduce drunk driving deaths from the levels of the early 1980s, messaging from the alcohol industry has continued to (mis)inform public health policy (Madden and McCambridge, 2021), with one result being that alcohol-related traffic deaths have nonetheless remained relatively flat - and far too high - for the past decade or so. The National Safety Council estimates that for the past 10 years, drunk driving crashes (BAC >0.08%) have continued to be responsible for approximately 30% of all crash fatalities in the US (Injury Facts, 2020), which equates to approximately 10,000 deaths every year (NHTSA, 2018). Thus, although significant inroads have been made in reducing drunk driving crashes and fatalities, drunk driving continues to claim the lives of far too many on our roadways.

The COVID-19 pandemic has had significant consequences on alcohol and drug use. Alcohol sales increased as people were required to become more homebound (NIIAAA, 2021), and now studies are showing increases in both the amount of alcohol consumed and in the number of days under the influence during lockdown phase of the pandemic (Pollard et al., 2020). With more and more states lifting of COVID restrictions on group gatherings on the horizon, an increase in group gatherings and travel - with a resulting increase in driving after drinking - is highly likely.

Currently, the Blood Alcohol Concentration (BAC) cut-off level for drunk driving is set at 80 mg/dl (0.08%) for most states in the USA. Research from many sources has shown that driving performance is impaired at even lower concentrations (see Zohr et al., 2020 for review). Several countries (SmartAdvocate, 2020) and the State of Utah (Utah Department of Public Safety, 2020) in the US have adopted a lower drunk driving BAC cut-off at 50 mg/dl, and several other states - including Hawaii, Virginia, New York and Michigan - have considered and debated legislation to reduce their BAC cut-off to 50 mg/dl (Zohr et al, 2020). Many groups such as the World Health Organization (3) and the National Transportation Safety Board (2) have supported this move. It has been estimated that lowering the drunk driving BAC cut-off to 50 mg/dl would save on average 500-800 lives every year in the US alone (NTSB, 2017).

Several studies have reported adverse effects of ethanol on road driving (Ramaekers et al., 2000), as well as simulator performance (Burns and Moskowitz, 1980; Kenntner-Mabiala et al., 2015; Hartman et al., 2015) These studies have used many measures, but one of the most commonly-used measures of drunk driving is the Standard Deviation of Lane Position (SDLP), essentially a measure of weaving while driving. Recently, our laboratory has used a driving simulator to study crash avoidance reaction time, a measure related to defensive driving ability. We have shown that both low dose

alcohol (BAC: 50-80 mg/dl) and marijuana (10 mg edible THC, blood concentration < 3 ng/ml) cause an increase in crash avoidance reaction time in this defensive driving task (Alali et al, 2020).

Driving simulators have also been used as educational tools regarding the hazards of distracted and impaired driving. For example, the APlusB simulator company has advocated for using portable simulators with a drunk driving program to provide educational experiences regarding the effects of alcohol on simulator driving performance (APlusB Inc, 2021) In addition, Innocorp has developed a hands on educational tool using go-carts and 'beer goggles' to help young drivers appreciate the hazards of drunk and impaired driving (Innocorp, 2021).

In addition to our academic studies on the effects of distractions (texting; Rumschlag et al, 2014; Palumbo et al, 2015) and drugs (Alali et al, 2020) on driving performance and driving safety, our research group also has been involved in public safety presentations to the community regarding the dangers of distracted driving and impaired driving. In the impaired driving presentations we have used a fixed-base driving simulator located in our college, with a 'demonstration subject' consuming real alcohol to achieve a measured BAC 50-75 mg/dl (not legally drunk in Michigan) and then demonstrating an impairment in crash avoidance driving performance. These hands-on demonstrations are an engaging and useful educational tool, but with a fixed base simulator (full size car in a laboratory room) they are limited to in-house presentations.

Recently, our research group started working with a portable driving simulator (Zohr et al., 2020), using Virtual Reality (VR) technology and specific software provided by Mahmoud Mattan at Brand XR (Orlando, FL). Before the COVID-19 outbreak, it was our plan to take this portable system "on the road" - figuratively speaking - for hands-on community informational presentations about the hazards of buzzed and/or drunk driving. Imagine, for example, a community leader in your town - the Mayor or the Chief of Police - 'driving' (in an auditorium in a 'town hall' setting) a VR-based simulator (described below in detail) and providing a first-hand demonstration of how even low doses of alcohol can adversely affect your driving ability. (Of course they would have a designated driver for the trip home afterward). Since we cannot take our presentation to the community during the

pandemic, we are sharing it at this time with the readers of Substance Abuse Treatment, Prevention, and Policy. The testing procedure is fun and easy to learn and, as we shall demonstrate, is highly sensitive to the disruptive effects of ethanol on driving performance. **Thus, the present paper describes a hands-on public awareness outreach program for demonstrating the hazards of (real) drunk driving, and the relationship between BAC levels and driving performance. The present paper also demonstrates very clearly the impairing effects of ethanol on driving even when the BAC is less than 80 mg/dl, i.e., the legal cut-off for drunk driving in most states in the US.**

Materials and Methods

Subject. Rather than the Mayor or the Chief of Police from the local municipality, the subject for this study is Dr. Commissaris, the project Principal Investigator. At the time of the study he weighed 205 pounds and had a body mass index (BMI) of 26. The subject has a history of occasional drinking, i.e., up to two alcoholic drinks/day socially as frequently as 2-3 times per week for the past six months. Except for his participation in the present study, he has not consumed more than 4-5 drinks in a single setting in over 20 years. The studies were conducted in accordance with Wayne State University IRB #066716B3E. (Normally, i.e., in non-COVID times, i.e, with the current IRB, subjects would be male and female, across a range of ages. In addition, the subjects would be characterized via survey as occasional, moderate or relatively heavy alcohol users. This would allow for an analysis of the potential influence of alcohol tolerance.)

Apparatus. Figure 1 below depicts the subject and the test apparatus used in the present



study. Crash avoidance reaction time was the primary measure of driving performance. In this VR-based game-like procedure, the driver is instructed to drive 70 mph ('pedal to the metal'; a programming governor limits the top speed at 70 mph) and stay in the middle lane of a three lane road. At randomly-occurring times during the drive, a 'stalled car' instantly appears in the road ahead. The stalled car is too close (40 meters headway distance) to avoid a crash via braking; the only way to avoid crashing into the stalled car is to rapidly steer around the car. The steering response should be hard to the left or hard to the right, and is determined by the location of the stalled car, i.e., slightly right of center

or slightly left of center; the relative position of the stalled car is unknown to the driver.

Thus, this is a type of 'choice' reaction time measure. Figure 2 below is a cartoon depicting the nature of this choice reaction driving task.

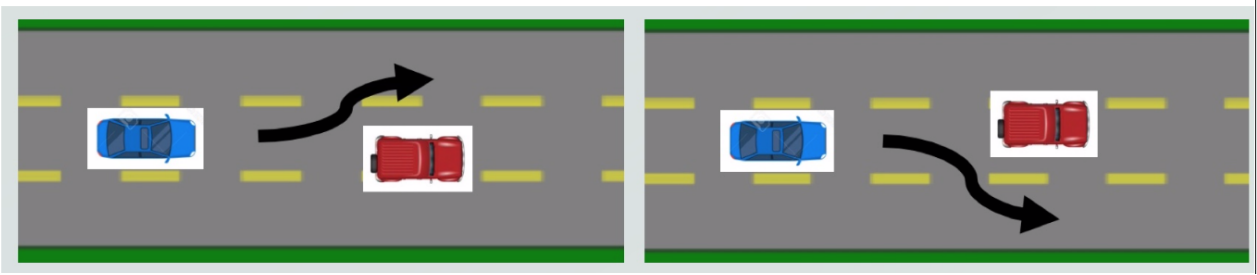


Figure 2. Illustration of the ‘go left’ and ‘go right’ trials utilized in the crash avoidance steering reaction paradigm. The driver (blue car) is traveling at 70 mph in the center lane and the ‘stalled car’ (red car) appears 40 meters ahead. The driver has to ‘read’ the situation and make a quick and sharp left or right turn to avoid a crash.

The primary measure of driving ability is the reaction time (in msec) to initiate an avoidance steering response, i.e., steering ≥ 5 degrees. Dr Commissaris is a highly experienced driver in this task, and he typically performs this crash avoidance response reliably (correct avoidances $> 99\%$ of all trials), with an average reaction time between 305-315 msec.

Procedure. On multiple occasions during a three-month period, each occasion separated by approximately 3-5 days, the laboratory group (via ZOOM meetings) conducted a study on the effects of alcohol or placebo (no drug) on crash avoidance reaction time using the VR-based driving simulator. All treatments (vehicle, 2 drinks, 4 drinks or 6 drinks) were ‘replicated’ on 4 occasions over the course of three months. On each of the treatment days the subject was tested in a pre-treatment drive, with subsequent drives conducted every 30 minutes after treatment for a period of 4-6 hours, depending on the treatment. For the alcohol treatment days, drives were immediately preceded by estimations of BAC using the BAC track S80 personal use breathalyzer device (KHN Solutions, San Francisco, CA). Two BAC track devices were used; the BAC value recorded at each pre-drive time-point was the average of the two meter readings. The duration of the drive test is 5-7 minutes, so the pre-drive BAC determinations were closely connected with driving performance at that time.

Dependent Variables and Statistical Analyses. The dependent variables measured were: (1) the crash avoidance reaction time, defined as the time in msec from the appearance of the stalled car until the steering wheel was turned ≥ 5 degrees and (2) BAC, measured

using the BAC Track devices. For the analysis of the time-course for the effects of different treatments on crash avoidance Reaction time, the data were analyzed using a 4 (Doses: Veh,2,4,6 Drinks) x 7 (Time: Pre-Tx,30,60,90,120,150,180 minutes) Factorial ANOVA, with the time as a repeated measure. Analysis of the time-course for alcohol concentrations versus treatments, the data were analyzed using 4 (Doses: Veh,2,4,6 Drinks) x 6 (Time: 30,60,90,120,150,180 minutes) Factorial ANOVA, with the time as a repeated measure. Reaction times for various BAC concentration groups were analyzed using a One-way ANOVA with four levels (0.0 mg/dl {Pre-Tx}, 10-49.9 mg/dl, 50-79.9 mg/dl, \geq 80 mg/dl) irrespective of dose administered. In all comparisons, $p < 0.05$ was the criterion for statistical significance.

Results

Figure 3 below illustrates the typical raw data generated for this crash avoidance steering response two hours after treatment with a relatively high dose of ethanol (6 drinks = 9 ounces of 80 proof vodka; red line) or vehicle (blue line). This figure depicts the steering wheel response (absolute value) as a function of time after the appearance of the stalled car. Steering wheel activity is sampled 120 times/sec with this device, so each point along the x-axis represents steering wheel activity (y-axis) during the first 500 msec following the appearance of the stalled car, separated into approximately 8.3 msec epochs. As can be seen, even when sober (vehicle curve) there is a significant delay for the initiation of a steering avoidance response. Using the criterion of 5 degrees steering as the operationally-defined initiation of a significant avoidance response, the time for initiation of a significant steering response was approximately 310 msec after vehicle treatment, but increased dramatically - to over 430 msec - two hours after the subject had consumed 6 alcoholic drinks (red trace). Statistically, there was a significant main effect for ethanol treatment ($F[1,24]=131.62, p<0.05$) and for Time (8.33 msec steering epochs) ($F[59,1416] = 311.84, p<0.05$); the ethanol treatment x Time interaction also was significant ($F[5,1416]=85.69, p<0.05$).

Crash Avoidance Steering Response

Current effect: $F(59, 1416)=85.689, p=0.0000$

Effects of Ethanol (6 Drinks) versus Vehicle

Symbol and vertical bars denote Mean \pm SEM; tested 120 minutes after treatment

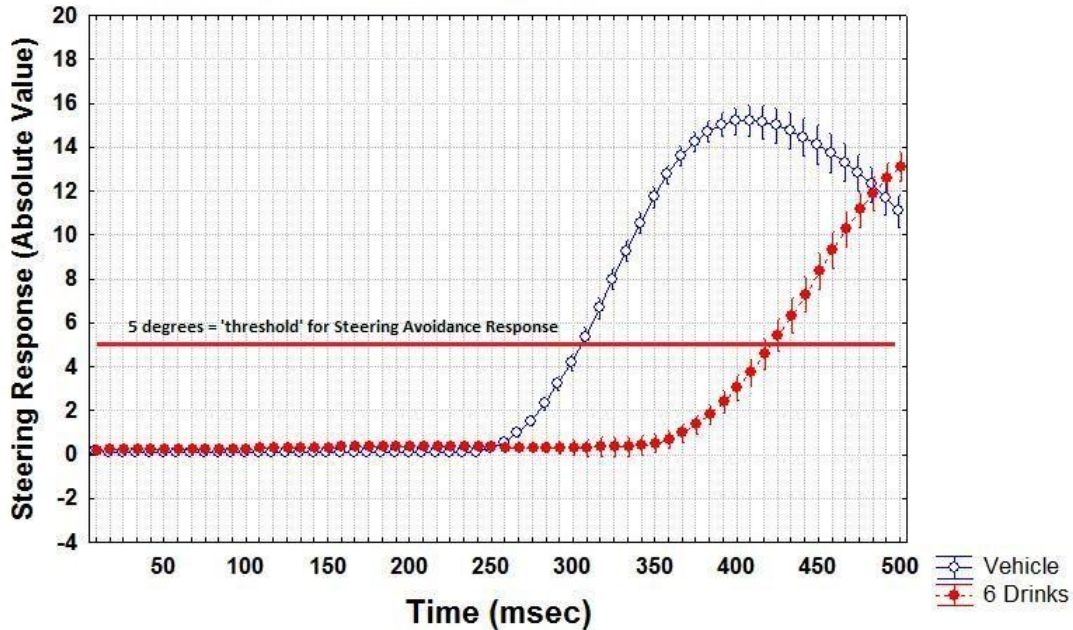


Figure 3. Time course for the crash avoidance steering response following either vehicle or 6 drinks (9 ounces of 80 proof vodka). Plotted are the Mean \pm SEM values for steering wheel activity over the course of the first 500 msec following presentation of the stalled car. The absolute value of steering was used to normalize for right (positive values) and left (negative values). As can be seen, following vehicle treatment no response is apparent until at least 250 msec and the threshold for steering response (defined as turning ≥ 5 degrees) was reached at approximately 310 msec. These values were significantly and dramatically increased following high-dose alcohol treatment (see text for details).

Figure 4 below illustrates the time course for the effects of different doses alcohol. In this graph, the y-axis is the mean crash avoidance reaction time in msec, i.e., the time to initiation of a 5 degree steering response; the x-axis is the time (in 30-minute epochs) after treatment with vehicle, 2, 4 or 6 drinks. As can be seen, vehicle treatment had no effect on crash avoidance reaction time. Alcohol significantly increased crash avoidance reaction time in both a dose-dependent and time-dependent manner. Statistically, there was a significant Main Effect for Ethanol Dose ($F[3,10]=56.61, p<0.05$) and a significant Main Effect for Time ($F[6,60]=16.49, p<0.05$); and a significant Ethanol Dose x Time interaction ($F[18,60]=6.97, p<0.05$). Post hoc Student Newman Keuls (SNK) tests revealed significant increases in reaction time (compared to vehicle treatment) following 4 drinks or 6 drinks at several times post-treatment.

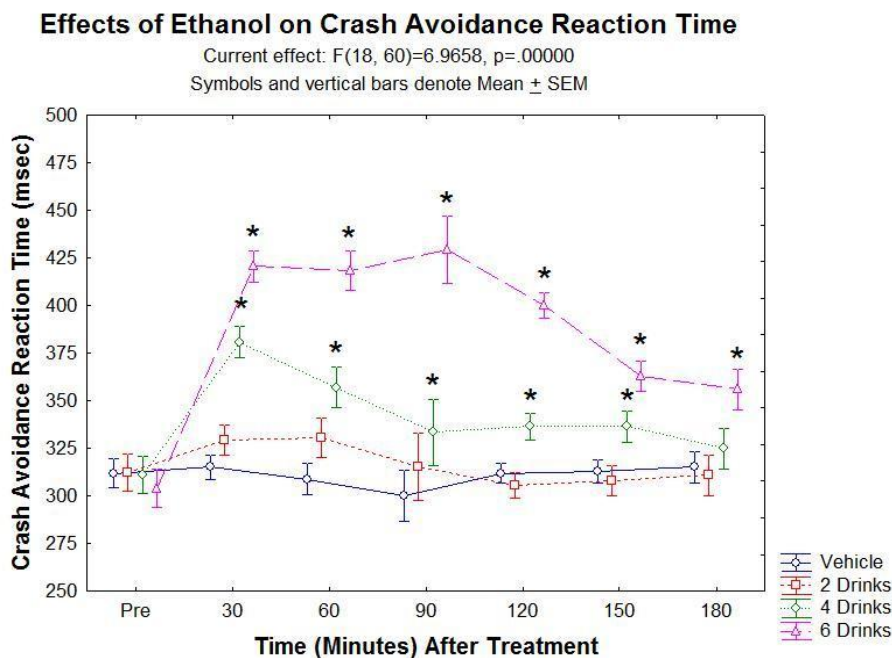


Figure 4. Time course for the effects of alcohol on crash avoidance reaction time. Plotted are the mean \pm SEM values for crash avoidance reaction time before (Pre) and at 30,60,90,120,150 and 180 minutes following treatment with 0 (Vehicle), 2, 4 or 6 drinks of alcohol (see text for further details).

* - reaction time at the indicated test time is significantly different from Pre-Tx value for that treatment, Student Neuman Keuls (SNK) test following factorial ANOVA.

Figure 5 below depicts the dose-response plot for the effects of ethanol on crash avoidance reaction time for the period 30-180 minutes post administration. As can be seen, ethanol produced a dose-dependent increase in crash avoidance reaction time. Statistically, there was a significant effect of Ethanol dose ($F[3, 10]=64.60$, $p<0.05$); post hoc SNK comparisons revealed that both 4 drinks (6 ounces of vodka) and 6 drinks significantly increased crash avoidance reaction time when compared to vehicle-treated controls over the same period.

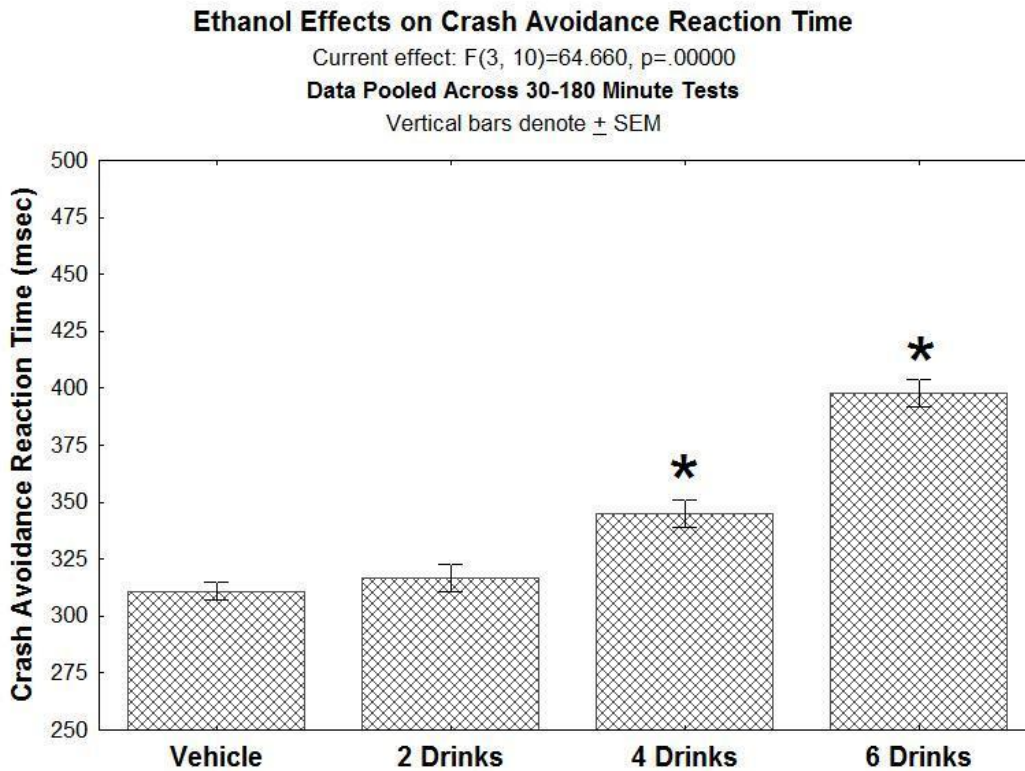


Figure 5. Dose-response for the effects of alcohol on crash avoidance reaction time, 30-180 minutes following treatment. Plotted are the mean \pm SEM values (pooled across the period 30-180 minutes post-treatment) for crash avoidance reaction time following treatment with 0 (Vehicle), 2, 4 or 6 drinks of alcohol (see text for further details).

* - reaction time for the indicated treatment is significantly different from Vehicle controls, Student Neuman Keuls (SNK) test following factorial ANOVA.

BAC concentration measurements using the two BAC Track devices were in strong agreement, with a correlation of $r=0.98$ across the multiple BAC determinations (data not shown). Figure 6 below depicts the ethanol concentrations for the 3-hour post-treatment period for the three ethanol doses. As can be seen, the peak ethanol concentration varied significantly with ethanol dose, but the fall in the concentration over time was similar across the three doses, consistent with the primarily zero order metabolism of ethanol (Pawan, 1972). Statistically, there was a significant Main Effect for ethanol dose ($F[2,6]=308.83$, $p<0.05$) and for time ($F[5,30]=43.58$, $p<0.05$); the ethanol dose x time interaction also was significant ($F[10,30]=2.32$, $p<0.05$).

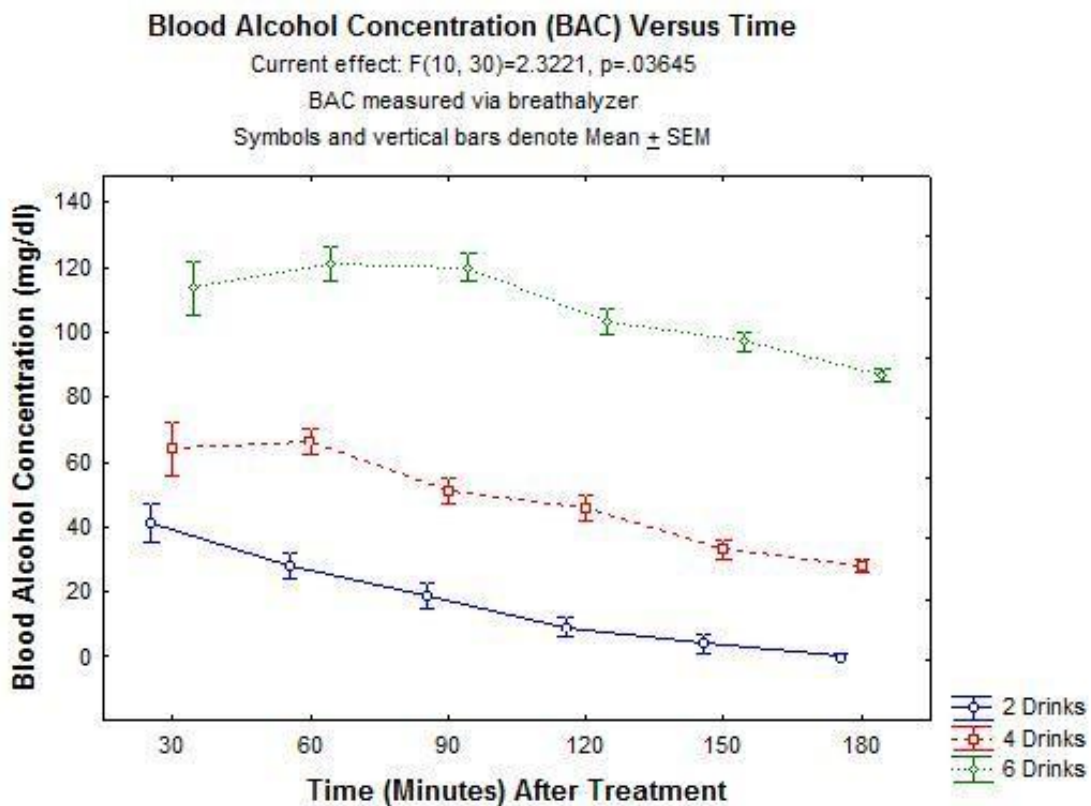


Figure 6. Ethanol concentration versus time curves for 2, 4 and 6 drinks. Plotted are the Mean \pm SEM values (mg/dl) for ethanol at 30,60,90,120,150 and 180 minutes following administration of 2,4 or 6 drinks (see text for further details).

Figure 7 below is a scatterplot depicting the relationship between BAC (> 10 mg/dl; the threshold for detection with the BAC Trak devices) and driving performance across multiple driving tests at various times following the alcohol treatments. As can be seen, there is a highly significant correlation ($r=0.854$; $p<0.05$) between BAC and crash avoidance reaction time across the full range of BAC levels.

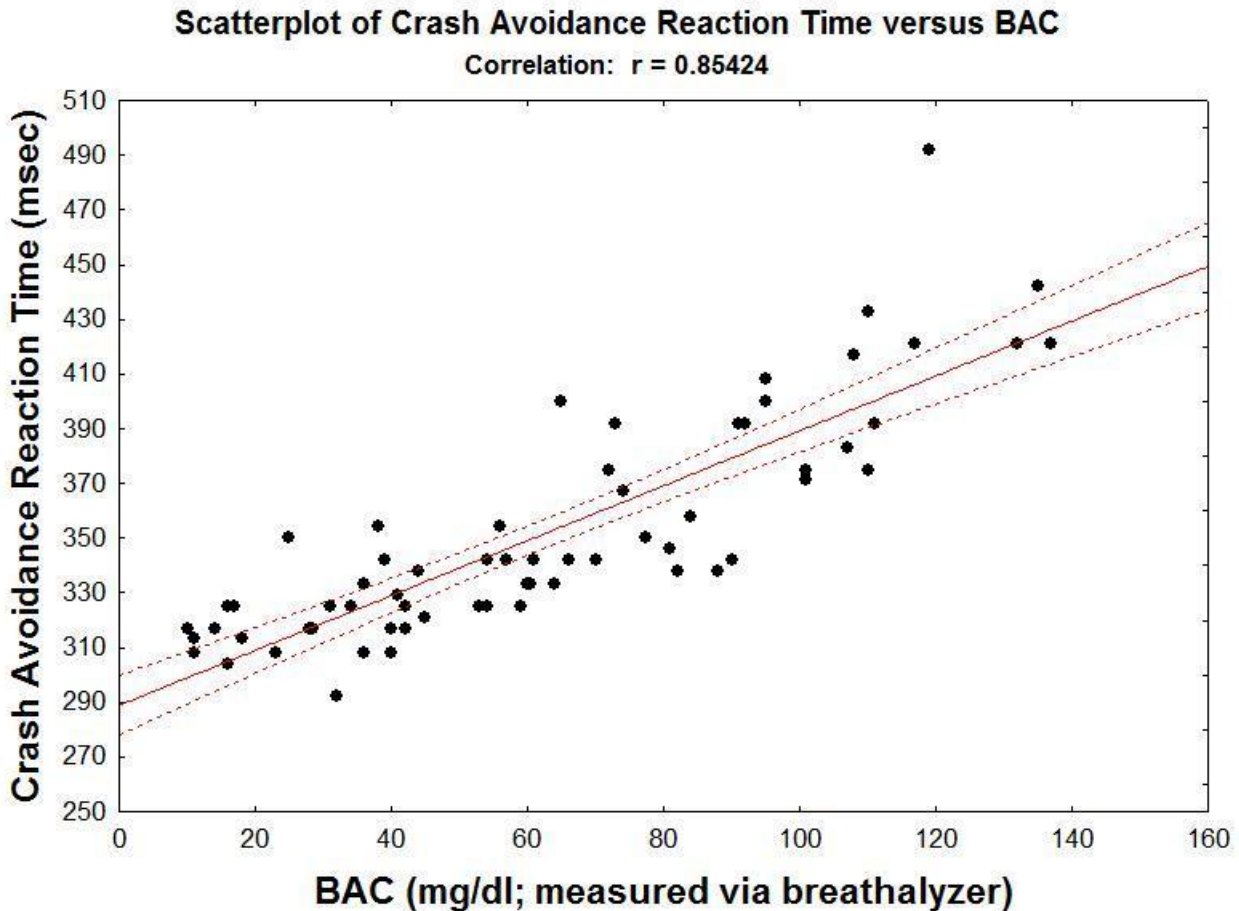


Figure 7. Scatterplot of crash avoidance reaction time versus BAC. Plotted are the individual values for crash avoidance reaction time across all test sessions and the correlated BAC values for those crash avoidance tests. BAC values of < 10 mg/dl were excluded because they register at 0 mg/dl on the meter. The Pearson correlation coefficient ($r = 0.85$) was statistically significant (see text for further details).

Finally, Figure 8 below illustrates crash avoidance reaction time when the data are grouped into various BAC categories: (1) 0.0 mg/dl, i.e., from Pre-Tx drives, (2) > 10 but less than 50 mg/dl, (3) \geq 50 mg/dl but < 80 mg/dl and (4) \geq 80 mg/dl. As can be seen, concentrations of 50-80 mg/dl significantly increased crash avoidance reaction time. Statistically, there was a significant effect for BAC category ($F[3,75]=40.75$, $p<0.05$); post-hoc SNK tests revealed a significant difference between Pre-Tx performance and both the BAC = 50-79.9 mg/dl group and the BAC \geq 80 mg/dl condition.

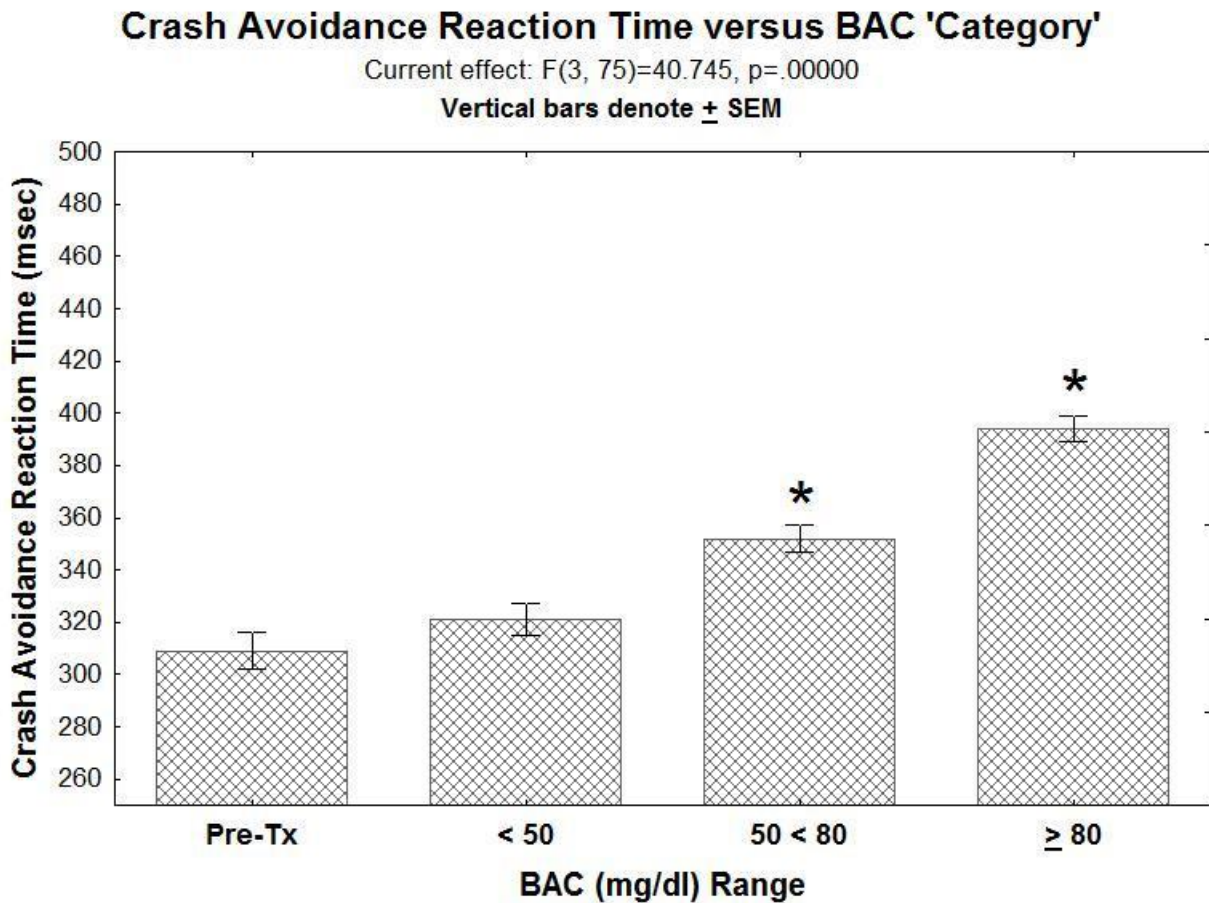


Figure 8. Crash avoidance reaction times for different BAC ranges. Plotted are the Mean \pm SEM values for crash avoidance reaction as a function of the BAC Range; BAC was determined immediately prior to the crash avoidance test.

* - Statistically different from Pre-Treatment control values (BAC = 0 mg/dl), SNK test following one-way ANOVA.

Discussion

The present paper describes the effects of alcohol on driving performance using a portable VR-based driving simulator choice reaction task for assessing defensive driving skills. The procedure is fun and easy to learn, and crash avoidance reaction times are robust and reliable using only a single demonstration subject. As expected, crash avoidance reaction time was increased by alcohol treatment in a dose- and time-dependent manner. Breath-based BAC determinations conducted immediately before testing revealed a strong correlation between BAC and crash avoidance reaction time. Finally, analysis of the crash avoidance reaction time based on the range of pre-drive BAC values revealed a significant increase in crash avoidance when BAC values ranged between 50-79.9 mg/dl, with an even greater increase in crash avoidance time when BAC values were ≥ 80 mg/dl, i.e., what is currently considered 'alcohol intoxicated' in most US states.

The present results support the argument that BAC values of $50 < 80$ mg/dl should be included as part of the the legal cut-off for drunk driving. This argument has been argued by several driving safety organizations (see Zohr et al., 2020) and has been supported by the results of previous open road (Ramaekers et al., 2000) as well as simulator studies (Burns and Moskowitz, 1980; Kenntner-Mabiala et al., 2015; Hartman et al., 2015). The present study is the first to demonstrate the adverse effects of these relatively low alcohol concentrations using a simulator-based defensive driving choice reaction task. Given that reaction time is critical for avoiding a crash in many defensive driving situations, the present results would translate to an impaired ability to engage effectively in defensive driving maneuvers, and thus would increase the likelihood of a crash at BAC values 50-80 mg/dl alcohol. These findings are consistent with studies that have demonstrated reduced alcohol-related crashes after the legal BAC cut-off for impaired driving was reduced to 50 mg/dl (NTSB, 2017). As has been argued previously (Zohr et al., 2020), from a policy and legal perspective, it also makes sense for the penalty for driving with a BAC 50-79.9 to be less severe than the penalty for driving with a BAC ≥ 80 mg/dl.

The second conclusion is more of a prediction, which is that public, hands on demonstrations using this VR-based driving simulator procedure - or something similar -

could be a powerful, cool and user-friendly tool to use in combating the problem of drunk and buzzed driving, especially among younger drivers. A somewhat similar approach utilizing go-cart driving and 'beer goggles' has been promoted by the Innocorp Corporation as a way to increase appreciation of the dangers of drunk driving (Innocorp, 2021). Similarly, we have used beer goggles in both research projects (Palumbo et al., 2015) and in public service presentations ("Don't text and drive in the motor city") to demonstrate how visual disturbances can exacerbate distracted driving problems (i.e., texting while driving). Although useful, these beer goggle approaches focus only on the visual problems produced by alcohol (and other drugs) and yet, as demonstrated in the present study, other effects of alcohol like those on reaction time, are also critically important for safe driving.

In terms of implementing law and policy changes, sometimes seeing is believing is the first step. As recalled by retired Los Angeles Police Department (LAPD) officer Thomas Page (personal communication), the value of a 'hands on' approach to understanding the effects of alcohol was demonstrated in the 1980s when officers from the LAPD met with a cohort of judges and prosecuting attorneys in LA County and got them intoxicated to a BAC level of 80 mg/dl, at a time when the BAC cut-off for drunk driving was then still 100 mg/dl. Experiencing the effects of 80 mg/dl for themselves, and seeing their colleagues experiencing the effects of 80 mg/dl, was strong evidence, and led to significantly increased support for implementation of the BAC 80 mg/dl cut-off (Thomas Page, personal communication). In a similar manner, a greater appreciation of the dangers of drunk driving, even when the BAC is less than the current legal cut-off for intoxicated driving (80 mg/dl in Michigan, for example), might come from hands on experience with the effects of alcohol using a driving simulator. We have beta-tested this 'hands on' approach in internet ZOOM presentations as part of a university class, and also for an advocacy group (Michael Tobias and the Michigan Coalition to Reduce Underage Drinking; mcrud.org) and a State of Michigan legislator (Legislative Director Megan Kiefer from the from the Office of State Legislator Abdullah Hammoud, Dearborn). We plan to take this portable VR-based driving simulator 'on the road' and bring "Move the BAC cut-off for drunk driving to 50 mg/dl" messaging (Zohr et al., 2020) to community groups as soon as possible after the current COVID-19 situation. This public outreach approach has been highlighted recently in a feature article in the Detroit News (Rubin, 2021).

The present study has several limitations. Perhaps first and foremost is the fact that only one subject was studied, and the study was conducted in an open label manner. This of course was a direct consequence of the COVID-19 epidemic, which prevented our research group from bringing additional subjects in for testing. In the present study, however, the subject was tested on multiple occasions with several doses of alcohol, and the effect clearly was reliably replicated in that subject. We should also add that we have tested a handful of additional subjects in a more limited manner, i.e., single doses, not a full time course, and observed comparable changes in reaction time with 4 drinks of alcohol and BAC levels between 50-80 mg/dl. Future studies in a post-COVID era, using placebo controlled double blind designs, will be used to confirm and expand upon the present findings. Another limitation is that the present study analyzed only one component of driving safety, i.e., the latency for a steering avoidance response to a potential crash situation. Although the debilitating effects of alcohol on this measure are clear and dramatic even at low ethanol concentrations, the effects of alcohol on other measures of driving safety, e.g., driving speed, braking time, decision-making, should be evaluated in future studies. Nonetheless, these studies demonstrate a significant impairment of defensive driving behavior at relatively low BAC levels.

Conclusions

In summary, this VR-based simulator task has a 'gaming' quality that makes it fun for many users - and even non-users - of VR-based gaming, but it also clearly demonstrates, with safety-relevant 'hard data' regarding crash avoidance reaction times, that even a few drinks can have significant adverse effects on driving performance and driving safety. Thus, the final take-home message is pretty clear: don't drink and drive, because even alcohol concentrations below the current drunk driving cut-off can significantly impair your driving performance.

Abbreviations:

- ANOVA: analysis of variance
- BAC: blood alcohol concentration
- BMI: body mass index

- IRB: institutional review board
- LAPD: Los Angeles Police Department
- Mph: miles per hour
- SDLP: standard deviation of lane position
- SEM: standard error of the mean
- SNK: Student Neuman Keuls
- THC: tetrahydrocannabinol
- VR: virtual reality

Declarations

Ethics approval and consent to participate. This study was reviewed and approved for human subjects use by the Wayne State University Human Subjects IRB Office (#066716BE3).

Consent for publication. Author RC gives consent for publication of Figure 1.

Availability of data and materials. The datasets during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests. The authors declare that they have no competing interests.

Funding. This project was supported by the Department of Pharmaceutical Sciences, the Eugene Applebaum College of Pharmacy and Health Sciences, and the Office of the Provost, Wayne State University, Detroit, MI 48202.

Authors' contributions. JA initiated the studies and wrote the first draft of the manuscript. JA, ZS, MM, EN, FM, TH, TZ, DH and RC participated in collecting the data and editing the manuscript. RC, JA, ZS, MM and TZ conducted the statistical analyses of the data and generated the figures. All authors read and approved the final manuscript.

Acknowledgements. Not applicable.

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Figures and Figure Legends



Figure 1. The subject and the testing apparatus.

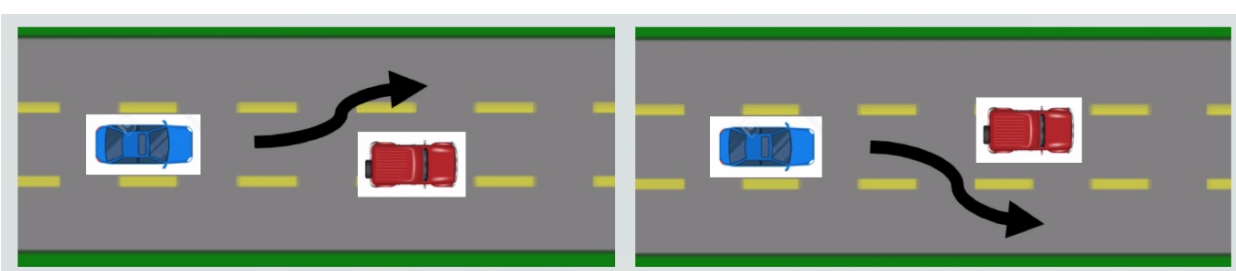


Figure 2. Illustration of the 'go left' and 'go right' trials utilized in the crash avoidance steering reaction paradigm. The driver (blue car) is traveling at 70 mph in the center lane and the 'stalled car' (red car) appears 40 meters ahead. The driver has to 'read' the situation and make a quick and sharp left or right turn to avoid a crash.

Crash Avoidance Steering Response

Current effect: $F(59, 1416)=85.689, p=0.0000$

Effects of Ethanol (6 Drinks) versus Vehicle

Symbol and vertical bars denote Mean \pm SEM; tested 120 minutes after treatment

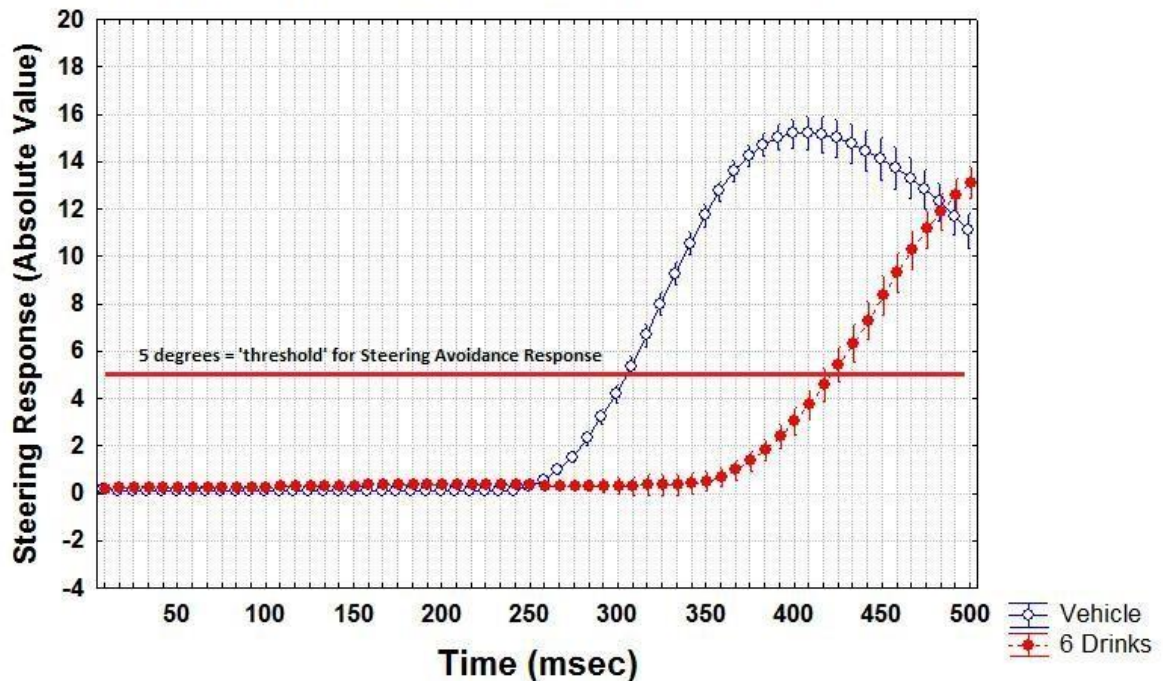


Figure 3. Time course for the crash avoidance steering response following either vehicle or 6 drinks (9 ounces of 80 proof vodka). Plotted are the Mean \pm SEM values for steering wheel activity over the course of the first 500 msec following presentation of the stalled car. The absolute value of steering was used to normalize for right (positive values) and left (negative values). As can be seen, following vehicle treatment no response is apparent until at least 250 msec and the threshold for steering response (defined as turning > 5 degrees) was reached at approximately 310 msec. These values were dramatically and significantly and dramatically increased following high-dose alcohol treatment (see text for details).

Effects of Ethanol on Crash Avoidance Reaction Time

Current effect: $F(18, 60)=6.9658, p=.00000$

Symbols and vertical bars denote Mean \pm SEM

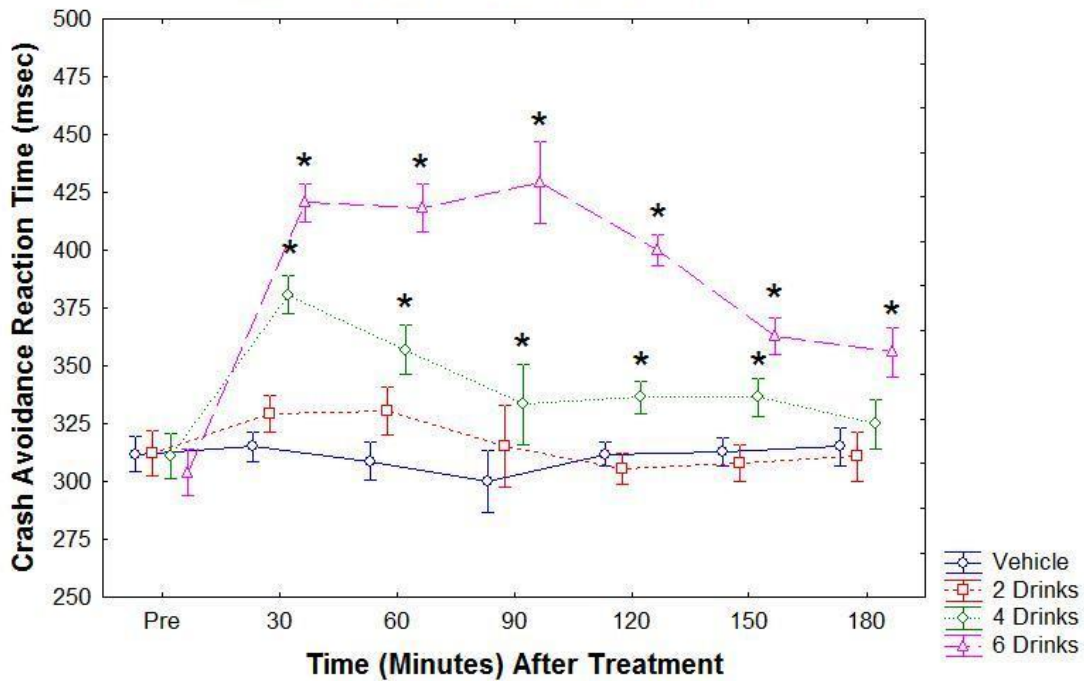


Figure 4. Time course for the effects of alcohol on crash avoidance reaction time. Plotted are the mean \pm SEM values for crash avoidance reaction time before (Pre) and at 30, 60, 90, 120, 150 and 180 minutes following treatment with 0 (Vehicle), 2, 4 or 6 drinks of alcohol (see text for further details).

* - reaction time at the indicated test time is significantly different from Pre-Tx value for that treatment, Student Neuman Keuls (SNK) test following factorial ANOVA.

Ethanol Effects on Crash Avoidance Reaction Time

Current effect: $F(3, 10)=64.660, p=.00000$

Data Pooled Across 30-180 Minute Tests

Vertical bars denote \pm SEM

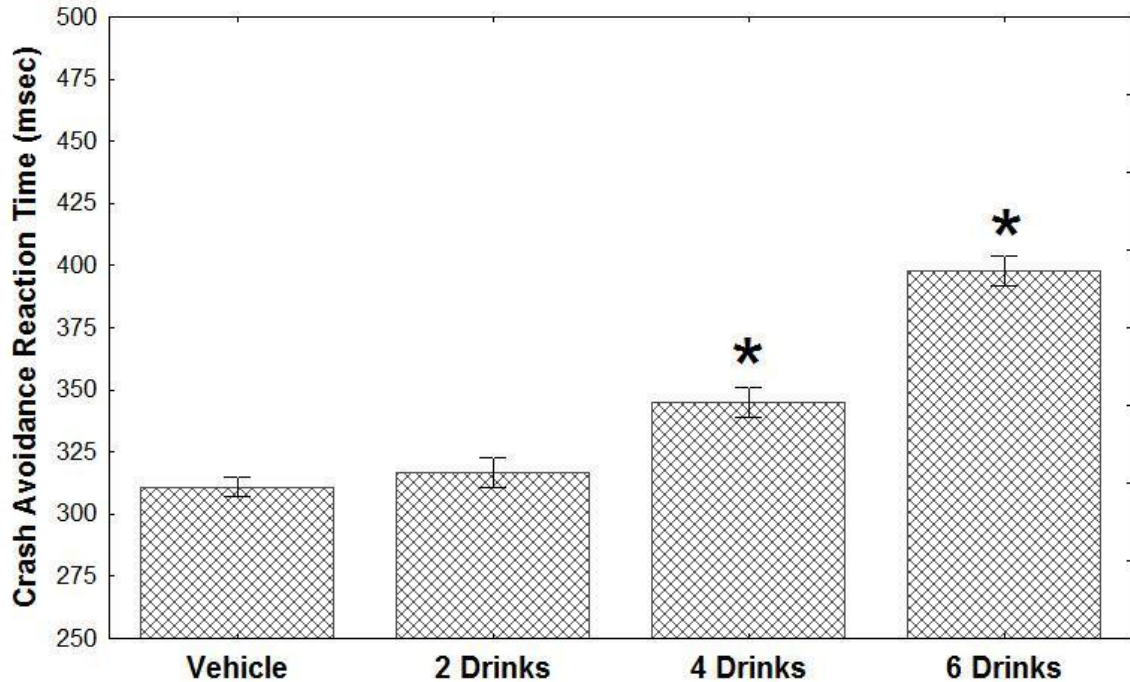


Figure 5. Dose-response for the effects of alcohol on crash avoidance reaction time, 30-180 minutes following treatment. Plotted are the mean \pm SEM values (pooled across the period 30-180 minutes post-treatment) for crash avoidance reaction time following treatment with 0 (Vehicle), 2, 4 or 6 drinks of alcohol (see text for further details).

* - reaction time for the indicated treatment is significantly different from Vehicle controls, Student Neuman Keuls (SNK) test following factorial ANOVA.

Blood Alcohol Concentration (BAC) Versus Time

Current effect: $F(10, 30)=2.3221, p=.03645$

BAC measured via breathalyzer

Symbols and vertical bars denote Mean \pm SEM

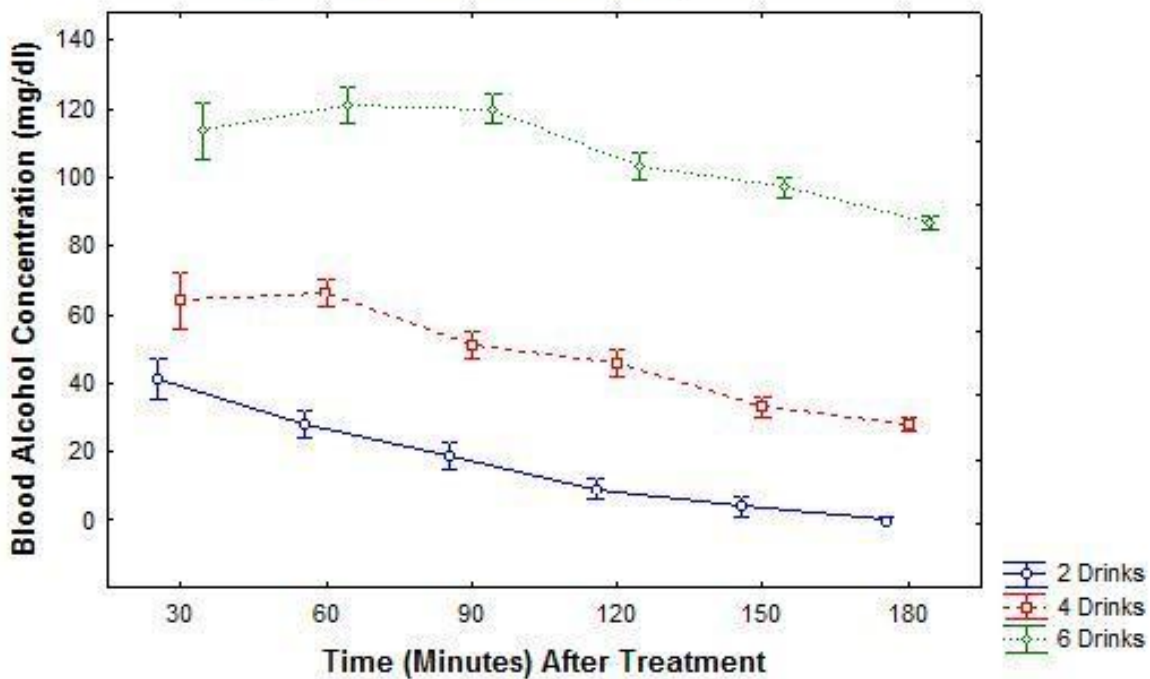


Figure 6. Ethanol concentration versus time curves for 2, 4 and 6 drinks. Plotted are the Mean \pm SEM values (mg/dl) for ethanol at 30,60,90,120,150 and 180 minutes following administration of 2,4 or 6 drinks (see text for further details).

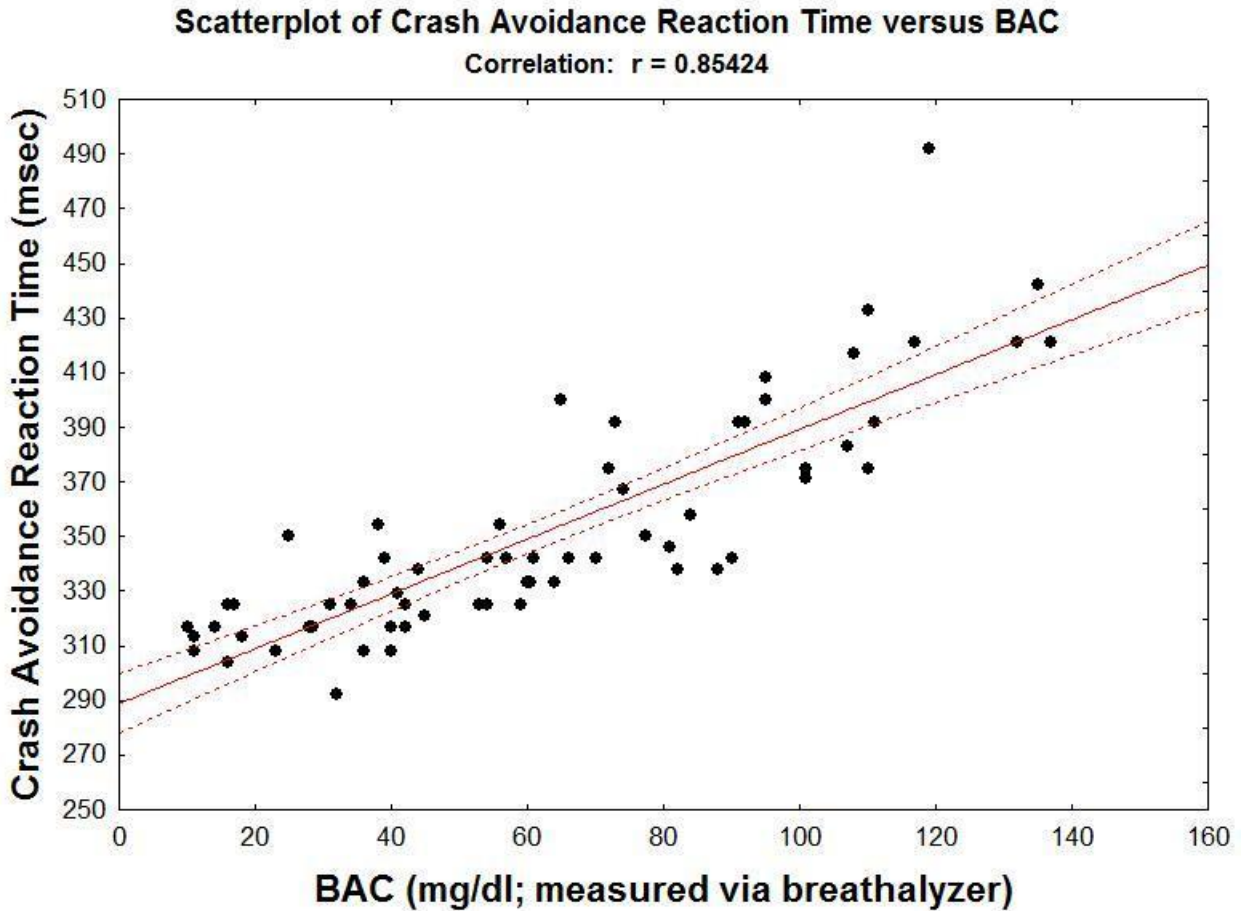


Figure 7. Scatter plot of crash avoidance reaction time versus BAC. Plotted are the individual values for crash avoidance reaction time across all test sessions and the correlated BAC values for those crash avoidance tests. BAC values of < 10 mg/dl were excluded because they register at 0 mg/dl on the meter. The Pearson correlation coefficient ($r = 0.85$) was statistically significant (see text for further details).

Crash Avoidance Reaction Time versus BAC 'Category'

Current effect: $F(3, 75)=40.745, p=.00000$

Vertical bars denote \pm SEM

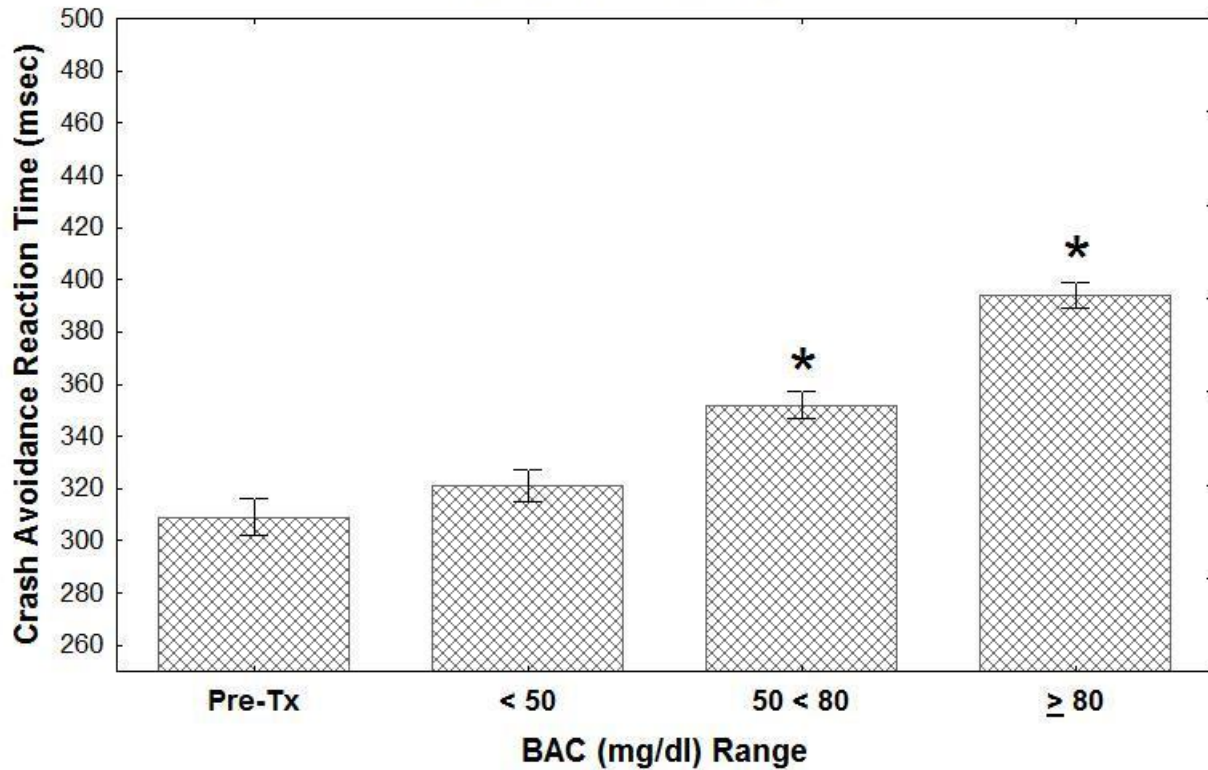


Figure 8. Crash avoidance reaction times for different BAC ranges. Plotted are the Mean \pm SEM values for crash avoidance reaction as a function of the BAC Range; BAC was determined immediately prior to the crash avoidance test.

* - Statistically different from Pre-Treatment control values (BAC = 0 mg/dl), SNK test following one-way ANOVA.