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Changes in Driving Behavior and Cognitive Performance with Different Breath Alcohol Concentration Levels

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Objective. This study examines the changes in driving behavior and cognitive performance of drivers with different breath alcohol concentration (BrAC) levels.

Methods. Eight licensed drivers, aged between 20 and 30 years, with BrAC levels of 0.00, 0.25, 0.4 and 0.5 mg/l performed simulated driving tests under high- and low-load conditions. Subjects were asked to assess their subjective psychological load at specified intervals and perform various tasks. The outcome was measured in terms of reaction times for task completion, accuracy rates, and driver’s driving behavior.

Results. The effects of BrAC vary depending on the task. Performance of tasks involving attention shift, information processing, and short-term memory showed significant deterioration with increasing BrAC, while dangerous external vehicle driving behavior occurred only when the BrAC reached 0.4 mg/l and the deterioration was marked.

Conclusion. We can conclude that the cognitive faculty is the first to be impaired by drinking resulting in deteriorated performance in tasks related to divided attention, short-term memory, logical reasoning, followed by visual perception. On the other hand, increasing alcohol dose may not pose an immediate impact on the external vehicle driving behavior but may negatively affect the driver’s motor behavior even at low BrAC levels. Experience and will power could compensate for the negative influence of alcohol enabling the drivers to remain in full steering control. This lag between alcohol consumption and impaired driving performance may mislead the drivers in thinking that they are still capable of safe steering and cause them to ignore the potential dangers of drunk driving.

Keywords Breath Alcohol Concentration (BrAC); Cognitive Task; Driver’s Behavior; Driving Simulator; Psychological Feeling

The worse combination of alcohol and driving makes it a tremendous threat to road users and has jeopardized traffic safety seriously. According to the National Highway Traffic Safety Administration (NHTSA) brief statistical summary, in 2004, 39% of the total traffic fatalities in the United States were alcohol-related. Similar results were found in other countries, for example, in 2003, 38.3% of fatally injured drivers in Canada were alcohol-involved (Traffic Injury Research Foundation of Canada, 2005), and in the United Kingdom, approximately 20% of road deaths were alcohol-related (Institute of Alcohol Studies, 2005). In Taiwan, 25.22% of the traffic accidents as well as subsequent fatalities (26.18%) and injuries (31.18%) were attributed to drunk driving (Directorate-General of Budget, Accounting and Statistics (DBAS), Executive Yuan, Taiwan, 2004). Many countries around the world have enacted laws prohibiting driving after alcohol ingestion and imposed severe penalties on violators. In Taiwan, the legal limit of blood alcohol concentration (BAC) is 0.05 mg/l or 0.25% using the Breath Alcohol Concentration (BrAC) as an indicator of alcohol ingestion. The transformation between BAC and BrAC follows Henry’s Law. Compared with other countries, such as England, Australia, 29 states in the United States, and most provinces in Canada whose legal limit is BAC = 0.08% (\(\sim BrAC = 0.40\%\)), the lower legal BrAC limit (BrAC = 0.25%) in Taiwan does not seem to arouse drivers’ awareness of alcohol driving. To decrease alcohol driving, the authors believe that the public needs to understand more about the impairments of alcohol driving. In addition, detecting drunk drivers instantly on the road may prevent them from taking chance to drive while being intoxicated. This study addressed the effects of alcohol upon drivers’ driving behaviors and cognitive performance, and tried to formulate feasible screening guidelines for law enforcement patrolling on the road.

Alcohol is known to affect the cognitive and neurological functions that can jeopardize the safety of both the driver and other road users (Finnigan & Hammersley, 1992). There are
abundant studies on the effect of alcohol on driver’s behavior and performance. Chamberlain and Solomon (2002) concluded their literature review by stating that regardless of the test setting, alcohol consumption, even at low doses, can affect driving skills, such as driver’s vision, steering wheel control, braking behavior, and vigilance, negatively. In particular, the information processing and divided attention work of the drivers are more heavily affected.

American Automobile Association (AAA) pointed out in 1984 that it took a longer time for drunk drivers to focus on a specific area. In 1994, the National Institute on Alcohol Abuse and Alcoholism (NIAAA) showed that BAC levels between 0.03% and 0.05% interfere with voluntary eye movements and impair the ability to rapidly track a moving target. Fillmore and Vogel-Sprott (1994) found that impairment of performing a pursuit tracking could occur at a BAC level as low as 0.054%. According to the literature review of Moskowitz and Fiorentino (2000), driver’s visual ability, such as car following distance judgment (Horne & Baumber, 1991) and depth perception (Wang et al., 1992), are impaired at BACs of 0.058% and 0.047%, respectively. Nawrot (2001) found that alcohol intoxication impairs the perception of depth from motion parallax and the range of driver’s visual field as well. Drivers’ visual field narrows by 6% at BACs of 0.02%, and reduces up to 20% at BACs between 0.05% to 0.08% (Beirness, 1985).

Skilled psychomotor performance, such as steering and braking control, is also adversely affected by alcohol in a dose-dependent manner (Moskowitz et al., 2000). Linnola, Erwin, and Ramn (1980) indicated that the driver’s ability to control the steering wheel is seriously affected at BACs of 0.035%. Marked reductions in accuracy of steering wheel use are found at BACs of 0.06% (Smiley et al., 1986). Cormier (1995) also found a 30% decrease in braking response ability at BACs of 0.03%.

Alcohol also causes decline in drivers’ vigilance. In his research, Gustafson (1986) asked the subjects to press a switch as rapidly as possible upon hearing a tone of 1000 Hz at 90 dB. A tone of that magnitude might alert subjects and offset the effects of alcohol, particularly at low BACs. However, at BACs of 0.030% and above, impairment was reported consistently across all studies (for details, please see Table A4 in Moskowitz & Fiorentino, 2000). Williamson et al. (2001) compared the performance of drivers deprived of sleep for 28 hours and drunk drivers with different BAC levels and found that fatigue did not affect the driver’s visual search and logical reasoning tasks. However, all tasks including simple reaction times, unstable tracking, dual task, Mackworth clock vigilance test, symbol digit coding, visual search, sequential spatial memory, and logical reasoning were affected by alcohol and the negative effects were most pronounced at BACs from 0.05% to 0.1%.

Divided attention tasks were often adopted to examine whether alcohol consumption affects the drivers’ ability to carry out multiple tasks while driving. Most divided attention tests use a central tracking task and a peripheral visual search task. This approach is appropriate since it models the divided attention characteristics of driving; tracking can be considered analogous to maintaining lane position and visual search corresponds to monitoring the environment. Roehrs et al. (1994) used this configuration and measured impairment at BACs as low as 0.005%. Moskowitz et al. (2000) measured the effect of different BAC levels on driving behavior and divided attention task ability and found deterioration in over 50% and 82% of the participants at BACs of 0.02% and 0.06%, respectively. In other words, increasing BACs leads to decline in drivers’ performance.

Low- or medium-dose alcohol exposure prolonged the reaction time and undermined logical reasoning and shape discrimination (Barzelay, 1986). Indeed, alcohol had a particularly serious effect on information processing and short-term memory (Moskowitz & Fiorentino, 2000; Moskowitz et al., 2000; Finnigan & Hammersley, 1992) that resulted in longer reaction times and/or more errors (Tharp et al., 1974).

The aforementioned effects of alcohol augment the risk of driving, which intensifies with increasing BAC levels (Hurst, Harte, & Frith, 1994). The Keall, Frith, & Patterson (2004) found that the risk of having an accident causing injury or death increases exponentially while driving under the influence of alcohol.

In view of the deleterious effect of alcohol on road safety, the government in Taiwan has tightened its control on drunk driving by setting roadside checkpoints for routine breath-alcohol screening of drivers. Nevertheless, opinions over such measures differ. Ironically, there are only a few studies on the effects of alcohol consumption on driving behavior and performance using BrAC as the yardstick in Taiwan. Hence, this study aims to explore alcohol-impaired driving performance with respect to drivers’ visual perception, cognitive judgment, motor behavior, and psychological feelings. It is hoped that our findings can provide references for law enforcers to implement closer monitoring of drivers’ behavior and performance to prevent injuries and causalties caused by drunk driving.

**METHODS**

**Subjects**

According to the statistics of the Ministry of the Interior (DBAS, Executive Yuan, Taiwan, 2004), drivers aged between 20 and 30 years have the highest incidence of accidents. In view of the possible dangers involved in drunk driving, we kept our sample size small and chose only young drivers who are most representative of the accident-prone group.

In this study, eight licensed drivers (four 20–24 and four 25–30 years old) were recruited by face-to-face interviews. There were six males and two females, a gender ratio also close to that involved in traffic accidents (DBAS, 2004). All participants had normal mental well being, no heavy drinking habits, normal or corrected-to-normal vision (~0.9) and all passed the Ishihara Test for color blindness. Subjects also had normal hearing, meaning that they can carry on a conversation easily with the experimenter while driving at a speed of 100 km/h. None of the subjects had any experience with the driving simulator.

Each subject underwent four tests, at target BrAC of 0 mg/l, 0.25 mg/l (BAC = ~0.05%), 0.4 mg/l (BAC = ~0.08%) and 0.5 mg/l (BAC = ~0.10%). The BrAC levels were defined as the
subject’s breath alcohol concentration level when conducting the real driving test. The results of BrAC levels were not revealed to the participants. The reason for using no alcohol consumption instead of a placebo is that in reality most people should be aware of whether they are drinking alcohol or not. The real problem arises not out of people’s ignorance of what they are consuming but how much they have been drinking.

**Apparatus**

*Breath Alcohol Analyzer.* A breath alcohol analyzer (Lion Alcolmeter™ SD-400 (400; 07), Palmenco AB, Saltsjö-Boo, Sweden) used by the police authority in Taiwan for roadside routine breath alcohol screening was employed in this study for measuring subjects’ BrAC levels.

*Driving Simulator.* The interactive STISIM Model 300 low-cost, fixed-base driving simulator (Systems Technology, Inc. Hawthorne, Calif.) was used. The simulated vehicle cab, a VOLVO DL340, featured all the normal automotive displays and controls (e.g., steering wheel, brakes, and accelerator) found in an automatic vehicle. Visual driving scenes were projected onto a 120-inch screen with sound effects of the vehicles in motion broadcasted by two-channel amplifiers, three IBM-P4 PCs were used to control the simulator, scenario, and visual head-up display (HUD), respectively. The basic visual scenes created by the STI consisted of blue sky with two or three mountains on the horizon. The roadway was dark ash grey with yellow central lines and green curbs. Road signs, traffic signs, houses, and trees lined both sides of the road. The STI simulator is widely used in research and the validity of its results is high (publications collected on the website of System Technology Inc., 2005).

Driving information such as speed and instructions from the experimenter concerning tasks to be performed (detailed in Section 2.4) were projected on the head-up display (HUD) located at 3.1 meters in front of the driver. The vertical projection angle is between 6° and 12° below the driver’s horizontal visual line, and the HUD area is about 32 (w) × 22 (h) cm² (~15 in²). The display resolution is 800 × 600 dpi, and the presentation font (icon) size is 10 × 10 cm² (~1.8°).

**Alcohol Dose Calculation**

Alcohol dose consumed by the subjects to achieve the specified BrAC was calculated using the following formula (Watson, 1989):

\[
\text{Alcohol dose (g)} = [(10 \times \text{BAL} \times \text{TBW})/0.8] + 10 \times MR \\
\times (\text{DDP} + \text{TPB}) \times (\text{TBW}/0.8)
\]

(1)

where BAL is the blood-alcohol level, TBW is the total body water, MR is the metabolic rate generally set at 0.015 g/100 ml/h (Casbon et al., 2003), DDP is duration of the drinking period, and TPB is the time to peak BAL generally set at 0.5 h (Casbon et al., 2003; NIAAA, 1997). There is a gender difference between TBW as follows:

\[
\text{Men’s TBW} = 2.447 - 0.09516 \times \text{Age} + 0.1074 \\
\times \text{Height (cm)} + 0.3362 \times \text{Weight (kg)}
\]

(2)

\[
\text{Women’s TBW} = -2.097 + 0.1069 \times \text{Height (cm)} \\
+ 0.2466 \times \text{Weight (kg)}
\]

(3)

**Tasks**

To understand the effect of alcohol consumption on driver’s judgment, attention, comprehension, motor coordination, visual discrimination, and reaction time, the subjects were asked to perform the following tasks.

*Drinking.* The dose of alcohol (40% Vodka, Absolut Vodka 700 ml, Sweden) calculated for each subject was divided evenly into two drinks, which were to be consumed within 20 minutes. Simulated driving began 15 minutes post-ingestion. The breath alcohol levels were measured prior to the actual test to ensure that the target BrAC levels are achieved.

*Driving.* The motorway route of the driving simulator was divided into high- and low-load conditions and each section took about 20 minutes with a 5-minute break in between. During driving, subjects had to follow the speed limit, comply with all traffic rules and safety regulations, and complete the required tasks as fast as possible making as few mistakes as possible.

*Visual Tasks.*

1. **Divided attention task:** The sign appears on both sides of the road. The sign changes at random into or and remains on display for 5 seconds. Detecting the change in sign appearance, subjects were asked to switch the indicator in the same direction as the sign on display four times in each road section.

2. **Distance estimation task:** A “Beware of Pedestrian” traffic sign on the road right side. Subject had to determine the distance between the vehicle and the traffic sign. Approximately 15 seconds before the traffic sign appears (location differs according to the road speed limit requirement), a verbal cue “Traffic Sign” is given to prompt the subjects and they were to say “Here” when the traffic sign was at 5-second distance away to complete the task. The accurate distance time measure (started from the subject’s indication to the traffic sign frame out) was recorded. This task was repeated four times in each road section.

*Cognitive Judgment Tasks.* Information related to these tasks was displayed on the HUD for 5 seconds because drivers were found to require 3–5 seconds for receiving inputs from in-vehicle signing information systems (ISIS) (Collins et al., 1999). Two tasks were designed for this study.

1. **Arithmetic Task:** The sign “Start” was shown as a pre-alarm cue 5 seconds before the task. Examples of addition task to be performed are illustrated in Figure 1a. Each sign will remain on the HUD for 5 seconds, followed by a 5-second interval before the next sign is shown. Subjects had to complete the arithmetic tasks and answer orally. This task assesses the information processing power and short-term memory of the subjects. Four arithmetic tasks (two
additions and two subtractions) were performed by the subjects in each road section, with no questions repeated.

(2) Semantic judgment task: Similar to the arithmetic task, the “Start” sign was shown 5 seconds before the task. Following a 5-second interval, a sign with two Chinese words was displayed for 5 seconds and the subjects were asked to judge the semantic similarity of the words. If the two words had the same meaning (Figure 1b), the subjects were to say “Yes”; otherwise say “No” in response. Four semantic judgment tasks were performed by subjects in each road section, with no repetition of questions. This task evaluates the comprehension and word meaning differentiation capability of the subjects.

Scenario Descriptions
The driving scenarios required for this study were prepared with the scenario definition language (SDL Version 8.1). Table I shows two sections of the different driving loads designed according to the factors proposed by Liu and Wen (2004). The high-load and low-load sections were 37.19 km and 27.43 km long, with speed limits of 100 km/h and 70 km/h, respectively. Each scenario consisted of two 20-minute sections of either high-low or low-high order load conditions. This task was performed four times for each of the four test tasks mentioned above. The 16 (4 × 4) test tasks were randomly spaced over the high- and low-load sections at 1.2-minute interval. The same type of test task was repeated at ∼2.4-minute interval also. The task arrangements are designed to prevent drivers’ learning and expectation biases from confounding the trials.

Table I Factors for developing low/high driving load conditions

<table>
<thead>
<tr>
<th>Factors</th>
<th>Low-load road</th>
<th>High-load road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane width</td>
<td>4.1 m</td>
<td>3.67 m</td>
</tr>
<tr>
<td>Road type</td>
<td>Straight two-way lane</td>
<td>Curvy two-way lane</td>
</tr>
<tr>
<td>Number of easy curves</td>
<td>2 (3100 m radius)</td>
<td>18 (3100 m radius)</td>
</tr>
<tr>
<td>Number of sharp curves</td>
<td>4 (1500 m radius)</td>
<td>12 (1500 m radius)</td>
</tr>
<tr>
<td>Speed limit</td>
<td>70 km/h</td>
<td>100 km/h</td>
</tr>
<tr>
<td>Density of oncoming traffic</td>
<td>Low: 1 vehicle per 457 m on average</td>
<td>High: 5 vehicles per 9 m on average</td>
</tr>
<tr>
<td>Number of intersections</td>
<td>34</td>
<td>120</td>
</tr>
<tr>
<td>Density of houses</td>
<td>Low: 2 houses per minute on average</td>
<td>High: 20 houses per minutes on average</td>
</tr>
<tr>
<td>Location of roadside building</td>
<td>20 m from the roadside</td>
<td>3 m from the roadside</td>
</tr>
</tbody>
</table>

Experimental Design
This research employed a 2 (driving load) × 4 (BrAC levels) within-subject factorial design. The four BrAC levels used were 0 mg/l (Group A), 0.25 mg/l (Group B), 0.4 mg/l (Group C), and 0.5 mg/l (Group D). The counter-balanced design of experimental sequence of the eight subjects was adopted to ensure better accuracy and to avoid order-related effects. Hence, the eight subjects were divided randomly into four groups with two participants each. In addition, to avoid residual effects of alcohol dose and familiarity from the preceding experiment, each group performed the experiments at four BrACs, 0, 0.25, 0.4, and 0.5 mg/l at intervals of 1, 1, 3, and 5 days, respectively. Experimental schedules were arranged as shown in Table II.

Both objective and subjective data were collected. The dependent measures for assessing the impact of alcohol on driving behavior and performance are as follows.

Driving Performance. Objective data collected by the STI simulator included

(1) mean speed and speed variance (m/sec),
(2) variance in lateral lane position (m),
(3) variance lateral acceleration (m/sec²),
(4) variance in steering wheel angle (degrees),
(5) variance in brake force applied (m), and
(6) type and number of accidents such as collision into an oncoming car, the roadside, or a pedestrian.

Task Performance.

(1) Reaction times (sec): Reaction times for the tasks of distance estimation, arithmetic, and semantic judgments were recorded by the experimenter using a stop watch, while the divided attention tasks were recorded by the STI simulator. The reaction time for the task of traffic sign distance estimation was obtained by the total elapsed time minus the accurate distance in time measure. In this way, the shorter the reaction time, the greater the distance underestimated by the driver underestimated the distance; conversely, the greater the distance overestimated by the driver.

(2) Correct responses and accuracy rates (%): The number of correct responses for the tasks of arithmetic, semantic judgment, and divided attention were recorded by the experimenter using a checklist and the accuracy rates were calculated.


Table II  Experimental schedules for four groups counterbalanced with four BrAC levels and two driving load conditions at intervals of 1, 1, 3, and 5 days

<table>
<thead>
<tr>
<th>Group</th>
<th>Low driving load road</th>
<th>High driving load road</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1A 1 3D 9C 13B 15A 17D 23C 27B</td>
<td>IIA 1 3A 5D 11C 15B 17A 19D 25C</td>
</tr>
<tr>
<td>II</td>
<td>1B 3A 5D 11C 15B 17A 19D 25C</td>
<td>IIB 5B 7A 9D 13C 19B 21A 23D</td>
</tr>
<tr>
<td>III</td>
<td>1C 5B 7A 9D 13C 19B 21A 23D</td>
<td>IIIA 1D 7C 11B 13A 15D 21C 25B 27A</td>
</tr>
<tr>
<td>IV</td>
<td>1D 7C 11B 13A 15D 21C 25B 27A</td>
<td>IIIB 1D 7C 11B 13A 15D 21C 25B 27A</td>
</tr>
</tbody>
</table>

1Number in the first position represents the day sequence of conducting the experiment for each of the four groups, and the following alphabet represents the experimental BrAC level.

**Subjective Assessment.** Subjects were asked to provide subjective assessment of the psychological load before and after alcohol ingestion as well as after driving each road section. These subjective data were collected using a 4-point scale questionnaire, with 1 indicating “not at all”; 2, “low”; 3, “medium”; and 4, “high.” The questions probed into the subjects’ available attention resource, state of mind, feeling of time pressure, visual and auditory effort required, self-control ability, vigilance, efforts made for task completion, and self-confidence level.

**Data Analysis.** Collected data were analyzed by ANOVA using SPSS Version 10.0 and post hoc analyses were carried out by Scheffé method. The level of significance for all analyses was set $\alpha < 0.05$.

**Procedures**

Subjects were asked to have enough sleep the night before the experiment and to refrain from taking any food or drink that contains alcohol a day before. Two hours before the experiment, subjects were prohibited from consuming high-fat, high-sugar, or caffeinated substances which might affect alcohol absorption. Subjects’ breath was analyzed in the laboratory to ensure that their pre-test status was of zero-alcohol.

Subjects were instructed about the simulator, the experimental procedure and tasks to be performed and then given approximately, 5-minute practice driving (according to the speed limit requirement) to get familiar with the simulator control and the road environment (e.g., accelerator, brake, steering wheel, and the low- and high-load road visual scenes). Then, the subjects drove the other 5-minute road section while performing the secondary tasks (each task appeared twice randomly at an interval of ~30 seconds). During the first 2 minutes of each practice trial, an experimenter in the passenger seat would provide instructions if necessary. However, the experimenter evaluated subjects driving behaviors (e.g., speed acceleration and deceleration, and lane change), task performance (e.g., clearly understand the task requirements and respond properly), and asked their psychological status (e.g., feeling comfortable or not) when subjects drove into the last 3 minutes of each practice section.

When the evaluation results reached error-free and feelings of conducting this experiment became comfortable, the real trial then began. None of the subjects in this study were required to run the second practice driving. A written consent was signed by all subjects. A physician was on-call during the entire test duration for any emergencies.

Subjects filled the first questionnaire before the experiment began and their blood pressure, temperature, height and weight were measured for calculating the dose of alcohol required. Subjects consumed their calculated alcohol dose in 20 minutes to achieve the required BrAC as confirmed by the breath alcohol analyzer. Subjects filled out a second questionnaire and performed simulated driving test 15 minutes post-ingestion. After driving each section with a different alcohol load, subjects filled out the third and the fourth questionnaire, respectively.

Each subject received a cash reward of $50 (US) upon completion of the test. Subjects rested in a room and were served hot tea or juice after the test. If needed, subjects were escorted home and followed-up within a 24 hours post-experiment to ensure that they had suffered no adverse effects of alcohol.

**RESULTS**

**Subjective Assessment**

Subjects with higher BrAC levels of 0.4 and 0.5 mg/l (Groups C and D, respectively) experienced decrement in attention available and self-control ability, weakened vigilance, and less effort made for task completion under both driving load conditions (Table III). However, the differences due to various BrAC levels became more marked under low driving load conditions.

**Task Performance**

**Accuracy Rate.** A consistent decreasing trend in the accuracy rate of all test tasks with increasing BrAC levels was observed under both driving load (high and low) conditions (Table IV).

Table III  Psychological ratings for different BrAC groups under low and high driving load conditions

<table>
<thead>
<tr>
<th>Driving load</th>
<th>Question</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
<th>F(3,21)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Attention available</td>
<td>3.375 a</td>
<td>3.25 a</td>
<td>2.25 b</td>
<td>2.5 b</td>
<td>8.704</td>
<td>.0006</td>
</tr>
<tr>
<td></td>
<td>Self-control ability</td>
<td>3.75 a</td>
<td>3.125 b</td>
<td>3.125 b</td>
<td>2.025 b</td>
<td>4.657</td>
<td>.12</td>
</tr>
<tr>
<td></td>
<td>Degree of vigilance</td>
<td>3.125 a</td>
<td>3.375 a</td>
<td>3 a</td>
<td>2.5 b</td>
<td>6.607</td>
<td>.0026</td>
</tr>
<tr>
<td></td>
<td>Confidence in task completion</td>
<td>3.75 a</td>
<td>3.75 a</td>
<td>3.5 ab</td>
<td>2.875 b</td>
<td>4.655</td>
<td>.12</td>
</tr>
<tr>
<td></td>
<td>Auditory stress</td>
<td>1.375 a</td>
<td>1.5 ab</td>
<td>1.875 b</td>
<td>2.5 c</td>
<td>9.8</td>
<td>.003</td>
</tr>
<tr>
<td>High</td>
<td>Attention available</td>
<td>3.375 a</td>
<td>3.125 ab</td>
<td>2.75 ab</td>
<td>2.5 bc</td>
<td>3.980</td>
<td>.022</td>
</tr>
<tr>
<td></td>
<td>Self-control ability</td>
<td>3.625 a</td>
<td>3.125 ab</td>
<td>3.125 ab</td>
<td>2.625 bc</td>
<td>4.000</td>
<td>.021</td>
</tr>
<tr>
<td></td>
<td>Degree of vigilance</td>
<td>3 ab</td>
<td>3.25 a</td>
<td>3.25 a</td>
<td>2.375 bc</td>
<td>3.588</td>
<td>.031</td>
</tr>
<tr>
<td></td>
<td>Confidence in task completion</td>
<td>4 a</td>
<td>3.75 ab</td>
<td>3.5 b</td>
<td>3.5 b</td>
<td>6.725</td>
<td>.002</td>
</tr>
</tbody>
</table>

1Letters in the table denote post hoc analysis results. The same letter denotes insignificant difference in mean value between groups. A change in the order of the letter indicates deterioration in psychological rating.
Table IV  Accuracy rates (in percentage) of various tasks for different BrAC groups under low and high driving load conditions

<table>
<thead>
<tr>
<th>Task</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
</tr>
</thead>
<tbody>
<tr>
<td>High driving load</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arithmetic</td>
<td>100 (93.75)</td>
<td>90.63 (87.50)</td>
<td>81.25 (71.88)</td>
<td>84.38 (75)</td>
</tr>
<tr>
<td>Remember the first</td>
<td>100 (100)</td>
<td>75 (50)</td>
<td>62 (25)</td>
<td>50 (37)</td>
</tr>
<tr>
<td>arithmetic number</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Semantic judgment</td>
<td>93.75 (100)</td>
<td>90.63 (96.88)</td>
<td>90.63 (90.63)</td>
<td>81.25 (81.25)</td>
</tr>
<tr>
<td>Divided attention</td>
<td>93.75 (96.88)</td>
<td>90.63 (93.75)</td>
<td>75 (87.5)</td>
<td>65.63 (78.18)</td>
</tr>
<tr>
<td>Low driving load</td>
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</tbody>
</table>

Figure 2 displays the percentage decrease in accuracy rates of various tasks between no alcohol consumption (Group A) and all other BrACs (Groups B, C, and D). The short-term memory required for arithmetic task suffered the greatest impairment due to alcohol consumption while the semantic judgment task was least affected under both driving conditions. Significant difference in the accuracy of divided attention task with increasing BrAC was also observed, while the deterioration in arithmetic accuracy seemed to level off from BrAC of 0.4 mg/l (Group C).

Reaction Time. Table V displays the reaction times for each test task.

(1) Distance estimation task: Under both high and low driving load conditions, the difference in average reaction times at various BrACs was significant, (F(3,21) = 5.636, p < .01) and (F(3,21) = 10.584, p < .001), respectively. In other words, subjects with higher and lower (0 and 0.25 mg/l) BrACs tended to overestimate (longer reaction times) or underestimate (shorter reaction times) the relative distance of the vehicle from the traffic sign ahead.

(2) Arithmetic task: The difference in average reaction times at various BrACs was significant, (F(3,21) = 9.604, p < .001) and (F(3,21) = 8.433, p < .001) under both high and low driving load conditions, respectively. Deterioration in arithmetic accuracy tended to level off with increasing BrAC levels at high driving load but was impaired only at BrAC of 0.4 mg/l (Group C) at low driving load.

(3) Semantic judgment task: The difference in average reaction times at various BrACs was significant, (F(3,21) = 16.621, p < .0001) and (F(3,21) = 10.908, p < .001) under both high and low driving load conditions, respectively. Subjects with no (Group A) or low (Group B, 0.25 mg/l) BrAC showed little difference, but a marked increase in reaction times was evident at BrACs of 0.4 mg/l (Group C) and Group D (0.5 mg/l). These results indicate that alcohol exerts a negative impact on word meaning differentiation.

(4) Divided attention task: The differences in average reaction times at various BrACs were significant, (F(3,21) = 44.093, p < .00001) and (F(3,21) = 38.537, p < .00001) under both high and low driving load conditions, respectively. As can be seen, with increasing BrACs, longer time is needed to respond to sudden off-road events which require divided attention.

The percentage increase in reaction times for various tasks between no alcohol consumption (Group A) and all other BrACs (Groups B, C, and D) is shown in Figure 3. An increasing trend in the reaction times for performing various tasks with higher BrACs, indicating performance deterioration, was observed. The divided attention task was the most affected followed by the semantic judgment task. Alcohol-induced impairment of distance estimation and mathematical calculation also occurred but the impact was comparatively less obvious and the decrease in reaction times for both tasks leveled off at BrAC of 0.4 mg/l (Group C).

Driving Performance. Our analysis shows significant differences in lateral acceleration variance (Group B, 0.25 mg/l < Group D, 0.5 mg/l (F(3,21) = 5.083, p < .01) and steering wheel angle variance (Group B, 0.25 mg/l < Group C, 0.4 mg/l (F(3,21) = 3.922, p < .05) under high driving load condition,
indicates that high dose alcohol affected driver’s attention negatively in vehicle control.

Wierwille and Gutmann (1978) suggested that a difference in steering wheel angle of more than 6° indicates deterioration in steering performance or occurrence of shifted attention. We calculated the number of deviations in steering wheel angle above 6° per minute of driving for various BrACs under high and low driving load conditions (Figure 4). The deviations in steering wheel angle of more than 6° occurred mostly and more frequently at 0.5 mg/l than at other BrAC levels. However, the variance in lateral lane position, mean variability in speed control, and frequency of major lane deviation (half of the vehicle crossing either the central or border road line) show no significant differences at various BrACs.

DISCUSSION AND CONCLUSION

Our results, consistent with previous findings, provide evidence about the negative impact of alcohol consumption on drivers’ behavior and performance. Psychologically, drivers feel that high alcohol exposure will impair attention and self-control ability, reduce effort made for task completion, weaken vigilance, and increase sense of frustration (Table III). Deleterious effect of increasing BrACs on visual perception is revealed by decreased accuracy rates in detection of road signs (Table IV) and longer reaction times to sudden off-road events and overestimated distance from traffic signs (Table V).

With respect to comprehension and judgment, greater alcohol ingestion reduces short-term memory and increases error rates in information processing and word meaning differentiation (Table IV), thus prolonging reaction times for completion of related tasks (Table V). Comparatively, motor coordination of the drivers is less affected by increasing BrACs, with significant variance only in lateral acceleration and steering wheel angle deviation under high driving load condition.

In summary, our results show that increasing BrACs leads to greater impairment in task rather than in driving performance. In other words, though high alcohol consumption does cause potential danger due to attention overload or shifted attention, actual steering behavior is not greatly impaired. Our study did
not find great speed variability, poor or high tracking variance under the influence of alcohol. Therefore, we can conclude that increasing alcohol intoxication exerts a negative impact on the cognitive ability of the driver that may not necessarily result in deteriorated driving performance.

It is of interest to explore whether the harm caused by alcohol varies depending on the task and whether certain harmful effects are more immediate than others. Previous studies related to the effects of alcohol on human behavior and performance found that at an alcohol dosage of 0.4–0.5 g/kg, perceptual-sensory tasks were impaired the most, followed by cognitive tasks with psychomotor tasks being the least affected (Levine, Krammer, & Levine, 1975; Krüger, 1993; Holloway, 1994; Moskowitz & Fiorentino, 2000). Our results also reveal that changes in performance under alcohol consumption are task-dependent in agreement with others (Figures 2 and 3). Thus, we can conclude that the cognitive faculty is the first to be impaired by drinking, resulting in deteriorated performance in tasks related to divided attention, short-term memory, logical reasoning, followed by visual perception. On the other hand, increasing alcohol dose may not pose an immediate impact on the external vehicle driving behavior but may negatively affect the driver’s motor behavior even at a low BrAC levels. Experience and will power could compensate for the negative influence of alcohol enabling the drivers to remain in full steering control. Alcohol-induced impairment may appear at high BrAC of 0.4 mg/l as seen in Figure 4. This lag between alcohol consumption and impaired driving performance may mislead the drivers in thinking that they are still capable of safe steering and cause them to ignore the potential dangers of drunk driving.

The limitations of this study include the relatively small sample size, which undermines its statistical power and results in insensitivity in generating the external validity to other driver populations. In addition, the alcohol dose calculation (Watson, 1989) and alcohol consumption procedure (Casbon et al., 2003) were designed to reach the highest BrAC level within 0.5 to 1 hour (NIAAA, 1997). The duration of the test from alcohol consumption (20 minutes), rest (15 minutes) to simulated driving (two 20-minute sessions with a 5-minute break) totaled around 1 hour, during which the BrAC would rise to peak levels and then decline. The first BrAC measured 15 minutes post-ingestion were close to the target level.

However, the metabolic rate of alcohol consumption varies among individuals, and thus when and how the alcohol levels change inside the human body is unknown. These unknowns could affect the internal validity of our test procedures. Hence, it can be argued that the task performance obtained in this study is not the result of a “pre-set BrAC level.” Therefore, future work should focus on examining how changes in BrAC levels, from rise to decline, affect driving behavior and performance.

**IMPLICATIONS**

The results of this study have significant implications for traffic safety enforcement. Police are often alerted to possible drunk driving by unsafe steering behaviors such as speeding, overtaking, high tracking variability, and constant lane switching. However, our study shows that alcohol-induced impairment in driving only appears at certain high BrACs while increasing alcohol dose aggravates deterioration of cognitive and motor function. Hence, other behaviors should also be taken into account as signs of possible drunk drinking. For example, constant flickering of indicator light may imply impaired short-term memory and shifted attention; keeping too close or distant from the car in front or braking too early or late at the stop light may mean poor distance estimation; late starting at green light may indicate slow reaction to changes or deteriorated detection power; and giving too early or late indication for turning may suggest shifted attention or poor distance estimation. Law enforcers aiming to reduce accidents and ensure road safety should pay due attention to these behaviors, which can help screen potential drunk drivers and prevent alcohol-related accidents.

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