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Drinking and driving behavior at stop signs and red lights

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ABSTRACT

Alcohol is one of the principal risk factors for motor vehicle crashes. One factor that contributes to vehicle crashes is noncompliance with stop signs and red lights. The present experiment investigated the effects of alcohol and drinking patterns on driving behavior at stop signs and red lights. 28 participants participated in drinking and simulated driving sessions during which they received a moderate dose of alcohol (0.08% BAC) or a placebo. Simulated driving tasks measured participants' driving performance at stop signs and red lights in response to each dose. Results suggested that alcohol impaired the driver control of speed and direction and prolonged their simple and complex reaction time, which were exhibited by impaired speed and lateral control, longer reaction time when the lights turned yellow, and lower deceleration towards stop signs and red lights. Visual degradation may also occur under alcohol intake. It was also suggested that alcohol impaired non-binge drinkers more severely. To be specific, higher acceleration was observed in impaired non-binge drinkers.

1. Introduction

Alcohol is one of the principal risk factors for motor vehicle crashes. Over 10,000 motor vehicle fatalities in the United States involved alcohol, representing an average of one alcohol impaired driving fatality occurring every 52 min, in the year 2013 (NHTSA, 2014). There is a large body of evidence demonstrating that moderate doses of alcohol impair a broad range of the skills important to driving performance (Carpenter, 1962; Donovan et al., 1983; Holloway, 1994; Levine et al., 1975; Mitchell, 2016; Moskowitz and Robinson, 1987). Alcohol produces visual degradation (Harrison and Fillmore, 2005a), alters decision-making (Burian et al., 2002; Modell and Mountz, 1990), slows simple and complex reaction time (Holloway, 1994), and decreases hand steadiness (Laberg and Löberg, 1989). Laboratory studies have also shown that moderate doses of alcohol impairs driving performance in driving simulations (Moskowitz and Burns, 1990). Alcohol impairs driving precision (as evident by the impaired perception of speed, increased within-lane and speed deviation and stopping accuracy) (Allen et al., 2016; Perrine and Huntley, 1971; Harrison and Fillmore, 2005b; Marczinski and Fillmore, 2009; Mets et al., 2011; Stein and Allen, 1987), and the behaviors critical to the safe operation of vehicles, such as braking reaction time (Laurell, 1977; Liguori et al., 1999).

One factor that contributes to multiple-vehicle crashes at intersections, as well as those involving pedestrians, is noncompliance with traffic control devices such as stop signs and red lights. In 2012, 683,000 vehicles were involved in crashes at stop signs. Approximately one-third of these crashes resulted in injury and more than 7000 were fatal (NHTSA, 2013). Retting et al. examined the prevalence of stop sign and traffic signal running crashes in urban areas using police-reported crash data obtained from three cities (Akron, Ohio; New Orleans, Louisiana; and Yonkers, New York) and identified that, among running traffic control (e.g., stop signs, red lights, yield signs) crashes, stop sign running accounted for the largest proportion (41%), followed by red light running, which accounted for 24% of crashes (Retting et al., 1995). Alcohol involvement was reported in 62.3% of all single vehicle crashes in which the driver failed to obey the stop sign, compared to 31.9% in the failure to obey the traffic signal (Campbell et al., 2004). O'Donnel reviewed eleven studies which described the driver's drinking location prior to a specific alcohol-impaired driving incident. Most of these studies showed that more than 40% of those alcohol-impaired drivers have consumed their last drink on licensed premises (O'Donnell, 1985). Most on-premise establishments are located along urban roads, which drivers use directly after leaving a licensed premises before reaching another destination on an urban road or before merging onto a highway (State Liquor Authority, 2016). If these alcohol-impaired drivers could be identified at stop signs or red lights, it would be easier for the police to stop them on urban roads. As a result, much higher

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severity of alcohol-impaired driving accident on highways would be prevented.

Despite the large numbers of crashes at stop signs and traffic signals involving alcohol and their relatively severe nature, drinking and driving behavior at stop signs and traffic signals has not been the subject of much detailed research. Romano et al. reviewed stop sign violation data from police reports and indicated that the incidence of stop sign violation increases when the driver consumed alcohol (Romano et al., 2006). Retting et al. examined the prevalence of red light running crashes on a national basis and identified the characteristics of such crashes and the drivers involved (Retting et al., 1999). They found that red light runners were more likely to have consumed alcohol. There were only a few experimental studies on the drinking and driving behavior at stop signs and traffic signals. Quillian et al. have investigated the effects of alcohol on the percentage of complete stop and stopping duration at the stop sign using driving simulators and only obtained statistically significant results on the former measurement (Quillian et al., 1999). Rafaelsen et al. investigated driving behavior at red lights in a driving simulator study and found that alcohol increased response time when lights turned from green to red as well as when lights turned from red to green (Rafaelsen et al., 1973). In Fillmore et al. (2008)'s study, worse compliance to the red light and greater acceleration when the light turned from red to green under alcohol was observed, compared with a placebo (Fillmore et al., 2008). Worse compliance at traffic signals was also observed in Stein and Allen (1987)'s study (Stein and Allen, 1987). In contrast, Harrison & Fillmore and Veldstra et al. did not find any difference in the compliance to the red light between participants under alcohol and those who took a placebo (Veldstra et al., 2012; Harrison and Fillmore, 2011).

Another important variable that may be contributing to alcohol-related driving skill impairment is the drinking pattern. Drinking pattern is associated with the development of tolerance, which refers to diminution in effects of a drug occurring with the same dose of drug that is due to previous administration of the drug (Mitchell, 2016). Current studies have shown that experienced drinkers often demonstrate behavioral tolerance or less impairment from acute alcohol than lighter drinkers (Hollingworth, 1923; Goldberg, 2017; Fillmore and Vogel-Sprott, 1995; Fillmore and Vogel-Sprott, 1996; Evans and Levin, 2004; Zhao et al., 2010). These findings are consistent across many studies on measures of sensory perception, memory tasks, psychomotor tasks, and steadiness of gait or body sway. However, some studies reported that individuals with chronic and excessive alcohol consumption exhibit a number of cognitive deficits and problems in inhibitory control. These cognitive deficits were associated with impulsivity (Moselhy et al., 2001), impaired cognitive function in working memory tasks, pattern recognition tasks (Weissenborn and Duka, 2003), and vehicle control (Zhao et al., 2010), even in a sober driving situation. Currently, only a few studies have suggested an effect of drinking pattern on impairment in driving performance (Coldwell, 1958), and driving behavior at stop signs and red lights has not been addressed.

The overall objective of this research was to investigate the effects of alcohol intake on driving behavior at stop signs, as well as the combined effects of drinking pattern with a laboratory driving experiment. It was hypothesized that driver behavior including speed and lateral position control, stop sign and red light compliance, stopping accuracy and braking/acceleration control at both stop sign and red light were worse under alcohol condition compared with placebo. Binge driver may exhibit better control of speed, lateral position, stopping accuracy and braking/acceleration at stop sign and red light.

2. Methods

2.1. Participants

A total of 28 healthy participants (14 males, 14 females) between the ages of 21 and 36 years (Mean = 23.43, SD = 3.12) were included in the study. Participants were included if they had a valid driver's license for at least two years. Exclusion criteria were current or past drug use, positive alcohol breath test, being pregnant, physical or mental illness, currently taking medication for which alcohol is contraindicated, or having been involved in other substance abuse treatment services within the past year (or currently). All participants had normal or corrected-to-normal vision. State University of New York at Buffalo Institutional Review Board approved the study and volunteers received $10/h for their participation.

2.2. Self-reported measures

All participants were asked to complete a set of questionnaires before engaging in the driving task. The first questionnaire was designed to capture participant demographics (e.g., gender, age) and driving history (e.g., driving experience, annual mileage). Participants were also required to complete the Timeline follow-back (Sobell and Sobell, 1992), which assesses daily patterns of alcohol consumption over the past 3 months and includes measures of the number of drinks consumed each day. The measure provided an accurate retrospective account of alcohol use during that time period. Participants were classified as binge or non-binge drinkers on the basis of the widely used Wechsler definition of a binge-drinking episode, which is five or more drinks on one occasion for men and four or more drinks on one occasion for women (Substance Abuse and Mental Health Services Administration, 2007).

2.3. Apparatus

A STISIM® driving simulator (STISIMDRIVE M100K, Systems Technology Inc, Hawthorne, CA) was used in the study. This desktop driving simulator includes a Logitech Momo® steering wheel with force feedback (Logitech Inc, Fremont, CA), a throttle pedal, and a brake pedal. The driving scenarios were presented on a 27-inch LCD with 1920 × 1200 pixel resolution. Auditory feedback was provided by speakers and included the sound of the engine and braking. Whenever a collision occurred, a broken windshield was projected, and the sound of breaking glass could be heard.

2.4. Driving scenarios

Two 14-mile driving scenarios were developed for each session, which included vehicles, pedestrians, traffic lights, traffic signs (e.g., stop sign, speed limit), and buildings. Traffic signs were displayed 500 feet in front of the driver and traffic lights were displayed 1000 feet in front of the driver. Traffic signs were displayed 500 feet in front of the driver. The driving scenario consisted of various numbers of lanes (from 1 lane to 3 lanes) in each direction. Participants were instructed to drive safely, obey traffic rules, remain in the center of the rightmost lane and adjust their speed as if they were driving a real vehicle on the road.

Each driving scenario included two stop signs and three red lights. The speed limit was either 30 mph or 35 mph when the driver was within 2000 feet of a stop sign intersection, with only one lane in each direction. The speed limit was 45 mph when the driver was within 2000 feet of a red light intersection, with two lanes in each direction. There were crossing vehicles or crossing pedestrians at each type of intersection.

2.5. Experimental design and procedures

Applicants who responded to local advertisements were interviewed first by telephone. They were screened in terms of driving history, drinking history, health history, current health status, and use of alcohol and other drugs. Qualified applicants were told to refrain from alcohol for at least 24 h, from other drugs (except tobacco) for 72 h, and from food and beverages (except water) for 3 h prior to their appointment.

Participants were tested during two sessions, one with a placebo treatment and one with an alcohol treatment. The two sessions were separated by a minimum of 24 h and a maximum of 3 days and the order of the two sessions were counterbalanced. Written informed consent was obtained from each participant before the start of the first session. A urine drug screening was then performed to detect the presence of cocaine, marijuana, opiates, amphetamine, methamphetamine, phencyclidine, barbiturate and benzodiazepine; a urine sample pregnancy test was carried out for female participants. Alcohol use was examined using a breath analyzer, Intoximeters Alco-Sensor FST.

If they met the inclusion and exclusion criteria, participants had a 20-min practice session in the driving simulator in order to familiarize themselves with the driving simulator manipulation. Participants without simulator sickness were randomly assigned to a treatment order comprising two treatments: placebo or 0.08% BAC.

Next, participants would complete a set of questionnaires and went through the beverage administration. The amount of ethanol necessary to reach the desired BAC level was calculated on the basis of body weight and gender (Watson et al., 1981). The placebo dose consisted of 24oz (three 8oz cups) of tonic water plus 1 ml alcohol floating on top of the drink and rubbed on the glass rim in order to enhance treatment blinding. The alcohol dose was administered by adding alcohol (95%) mixed with tonic water (three 8oz cups). Participants had 6 min to finish each drink and the interval between each drink was 1 min. Participants were instructed to pace each drink evenly over the entire drinking period, and they were monitored by the experimenter who periodically advised them of the time remaining to complete each drink. After each intake (either placebo or alcohol), Participants were instructed to complete the Beverage Rating Scale to report their perceived alcoholic content of the beverages consumed in terms of bottles of beer containing 5% alcohol. The scale ranges from 0 to 10 bottles of beer, in 0.5 bottle increments.

Participants' simulated driving performance was tested at 30 min after drinking began. Blinded BAC measurements were performed before and after each driving test scenario. After the driving test, participants relaxed in a waiting room within the laboratory. Blinded BAC measurements were performed every 20 min until their BAC fell below 0.02%. The experimenter recorded the reading of the breath analyzer after each measurement and informed the participant once his/her BAC was below 0.02%. On the placebo tests day, a series of breath analyzer tests were performed in a similar manner, to enhance blinding of the participants. Participants could not see the reading of the breath analyzer during any measurements. Upon completing the second session, participants were paid and debriefed.

Behavioral measures from the driving simulator were automatically collected: time elapsed (s), speed (ft/s), acceleration (ft/s2), distance (Martin et al., 1993), and lateral position (Martin et al., 1993). These experimental driving data were used to calculate the dependent variables. The general driving performance measures were as follows: standard deviation of lateral position, magnitude of speeding, standard deviation of driving speed, and the number of accidents in each driving scenario. In details, accidents included crashes with vehicles, pedestrians crossing at intersections, and off road accidents.

Five measures including stop sign compliance, time length of complete stop, stopping distance, braking profile, and accelerating profile described driver behavior at stop signs. Stop sign compliance referred to how frequently the driver stopped completely at the stop sign in one driving scenario. Stop distance was a driver's true stop distance to the stop line. If the driver stopped before the line, stop distance was positive. Braking profile included mean deceleration, standard deviation of deceleration and maximum deceleration during the time the stop sign appeared and the subject vehicle reached the lowest speed at the stop sign. Accelerating profile included mean acceleration, standard deviation of acceleration and maximum acceleration for the first 10 s after the participant speeded up from the stop sign.

Six measures including red light compliance, stop distance, response time to the yellow light, response time to the green light, braking profile, and accelerating profile described driver behavior at red lights. In one driving scenario, red light compliance referred to how frequently the driver completely stopped at red lights, or if they did not completely stop but were before the stop line during the time when the light was red. Response to the yellow light referred to the first response time of the driver when the light turned from green to yellow. To be specific, response time to the yellow light referred to the time 1) to release the gas pedal if the driver's foot was on the gas pedal, or 2) to first apply the brake if the driver's foot was not on either pedal. Similarly, response to the green light referred to the driver's first response time when the light turned from red to green. To be specific, response time to the green light referred to the time 1) to release the brake if the driver's foot was on the brake, or 2) to first apply the gas pedal if the driver's foot was not on either pedal. Braking profile included mean deceleration, standard deviation of deceleration and maximum deceleration during the time the light turned from green to yellow and 1) the subject vehicle reached the lowest speed before the light turned green if s/he did not make a complete stop, or 2) the subject vehicle completely stopped. Accelerating profile included mean acceleration, standard deviation of acceleration and maximum acceleration for the first 10 s after the light turned from red to green.

2.6. Data analysis

Statistical analyses were carried out employing the SPSS statistical program (Norušis, 1994). Each participant had repeated measures with respect to dose (placebo vs. 0.08% BAC) x drinking pattern (binge vs. non-binge). Mixed effect models therefore were built to investigate the effects of dose and drinking pattern on drivers' general driving performance as well as compliance, time length of complete stop, stop distance, and accelerating profile at stop signs. Gender, age, driving experience, elapsed time, and dose order were treated as covariates. When analyzing the braking profile at stop signs, driving speed when the stop sign initially appeared was also treated as a covariate. Similarly, the effects of dose and drinking pattern on drivers' compliance, stop distance, response time to the yellow light as well as to the green light, and accelerating profile at stop signs were investigated with gender, age, driving experience, elapsed time, and dose order as covariates. When analyzing the braking profile at red lights, driving speed and distance to the light when the light turned from green to yellow were also treated as covariates. Lastly, the effects of dose and drinking pattern on drivers' beverage rating scales were investigated using the similar mixed effect model.

Speeds recorded within 1000 feet after the new speed limit initially appeared was excluded in order to remove the speed fluctuations caused by the new speed limit. Driving speeds recorded after the stop sign initially appeared or the light initially turned yellow, and before the driver was at least 1000 feet from the stop sign or red light intersection during the accelerating process were also excluded in order to remove the speed fluctuations caused by the stop signs or red lights.

Driver behaviors at stop signs were excluded if collisions happened on the subject vehicle between the time the stop sign initially appeared to when the subject vehicle arrived at the stop line. Driver behaviors at red lights were excluded if collisions happened on the subject vehicle between the time when the light turned yellow to when the subject vehicle reached the stop line. Driver response times were also excluded if the driver was pressing the brake pedal when the light turned yellow or if the driver was pressing the accelerator when the light turned green. By excluding these cases, it was possible to accurately calculate the response time responding to the yellow light and green light.

Table 1
Means and standard deviations for demographic and self-reported measures.

Variable	Binge (n = 14)		Non-binge (n = 14)		p
	M	SD	M	SD	
Sociodemographic factors					
Age	23.1	4.0	23.8	2.0	*ns*
Gender (% male)	64.3		35.7		*ns*
Weight (pound)	164.1	19.8	150.8	25.2	*ns*
Race (% Caucasian)	68.8		41.7		*ns*
Driving history					
Year license (years)	5.8	3.5	3.1	0.9	0.049
Annual mileage	5.0	2.2	3.4	2.7	*ns*
Drinking history (past 3 months)					
Continuous days of drinking	4.4	3.8	3.5	5.7	*ns*
Total number of drinking days	18.9	12.7	10.1	6.9	0.033
Total number of drinks	84.7	54.0	19.6	12.7	0.000
Number of drinking occasions per week	1.5	1.0	0.8	0.5	0.039
Highest number of dinks consumed in 1 day	8.4	2.1	3.6	0.6	0.000
Number of drinks per occasion	4.6	1.6	2.0	0.5	0.000

Note: Year license refers to the number of years since a driver obtained his or her first valid U.S. driver license; Annual mileage is a self-reported measure on a scale of 5 categories (e.g., less than 5000 miles, 5000–7500 mile, etc.).

3. Results

3.1. Descriptive statistics

Table 1 lists all demographic variables, driving history, and drinking history for participants classified as binge or non-binge drinkers. The table shows that 14 participants were classified as binge drinkers and 14 participants were classified as non-binge drinkers using the 5+/4+ criteria.

3.2. General driving performance

A significant main effect of dose on impairment of lateral maintenance was observed, $F(1, 24.734) = 10.461$, $p = 0.003$ (see Fig. 1). To be specific, alcohol intake significantly impaired lateral maintenance. Dose also had a significant main effect on the standard deviation of speed, $F(1, 15.064) = 19.021$, $p = 0.001$ (see Fig. 2). In detail, speed deviation was greater under alcohol compared with the placebo. Also, the effect of elapsed time was significant on lateral deviation ($F(1, 36.224) = 26.4061$, $p = 0.000$). No factors had a significant effect on the magnitude of speeding.The effects of dose ($F(1,29.579) = 11.529$, $p = 0.002$) and dose x drinking pattern ($F(1,32.245) = 7.494$, $p = 0.010$) were both significant on the number of accidents (see

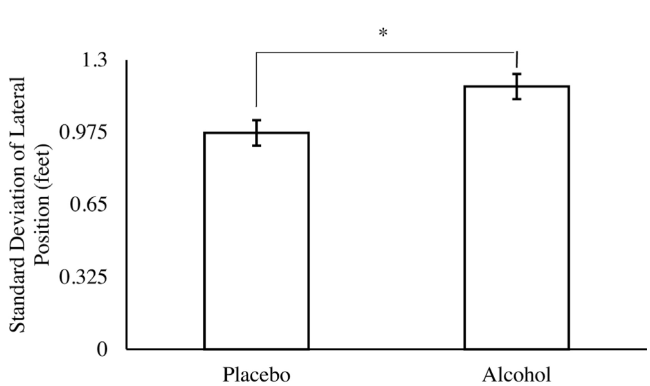

Fig. 1. Main effect of dose on standard deviation of lateral position. Vertical bars indicate the means (± 1SE) of standard deviation of lateral position.

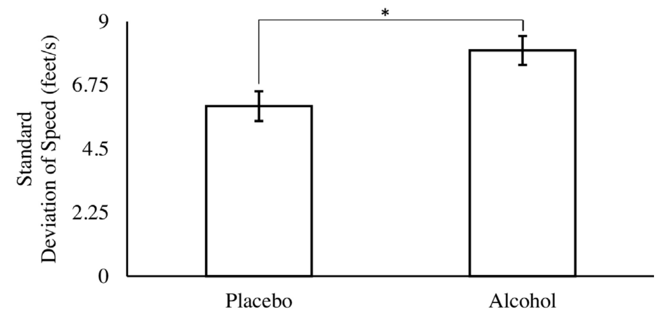

Fig. 2. Main effect of dose on standard deviation of speed. Vertical bars indicate the means (± 1SE) of standard deviation of speed.

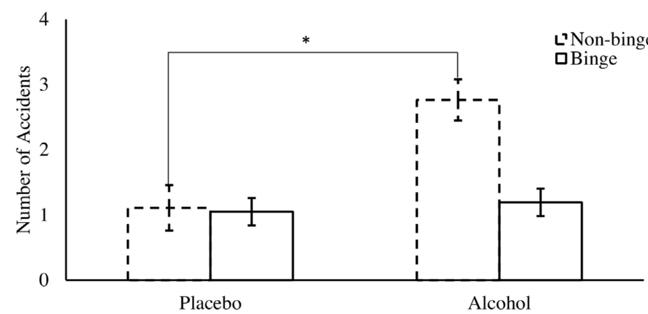

Fig. 3. Effects of dose and drinking pattern on number of accidents. Vertical bars indicate the means (± 1SE) of number of accidents.

Fig. 3). Alcohol intake caused more accidents. Also, compared with binge drinkers, a greater number of accidents was observed among non-binge drinkers. Simple effect analysis showed that more accidents were observed among intoxicated non-binge drinkers than intoxicated binge drinkers ($F(1,34.296) = 17.972$, $p = 0.000$).

3.3. Driving behavior at stop signs

3.3.1. Compliance, time length of complete stop, and stop distance

Neither dose, drinking pattern, nor any covariates had a significant effect on the compliance to stop signs or the time length of complete stop. Among the cases in which participants stopped the vehicle completely at stop signs, a significant main effect of dose was found on whether drivers stopped before the stop line ($F(1,165.397) = 5.019$, $p = 0.026$). To be specific, intoxicated drinkers tended to stop closer to the intersection compared with sober drivers, and a few intoxicated drivers stopped the vehicle beyond the stop line and collided with crossing vehicles or pedestrians. Elapsed time was found to significantly affect stop duration ($F(1,85.193) = 5.699$, $p = 0.019$).

3.3.2. Braking profile

Results showed a significant difference between mean deceleration values for sober and intoxicated drivers, with higher mean deceleration for sober drivers ($F(1, 187.412) = 12.042$, $p = 0.001$), (see Fig. 4). Dose also had a significant effect on the maximum deceleration ($F(1, 166.045) = 5.285$, $p = 0.023$) (see Fig. 5). Greater maximum deceleration values were observed among sober drivers compared with intoxicated drivers. In addition, driving speed had a significant effect on mean deceleration ($F(1, 198.796) = 859.183$, $p = 0.000$). The effects of driving speed when the stop sign appeared and elapsed time on the standard deviation of deceleration were also significant, $F(1, 204.021) = 20.959$, $p = 0.000$, $F(1, 107.594) = 5.769$, $p = 0.018$, respectively. Moreover, the effects of driving speed and elapsed time on maximum deceleration were also significant, $F(1, 202.800) = 6.341$, $p = 0.013$, $F(1, 41.343) = 14.892$, $p = 0.000$, respectively.

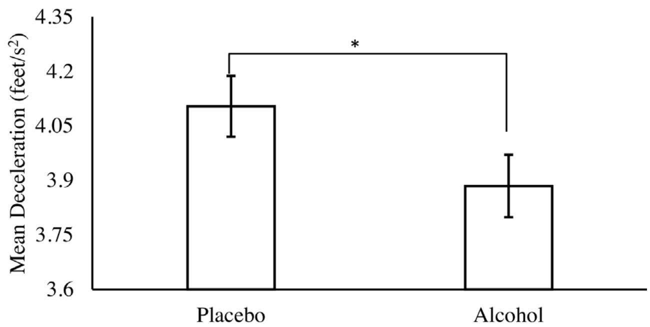

Fig. 4. Main effect of dose on mean deceleration. Vertical bars indicate the means (± 1SE) of mean deceleration.

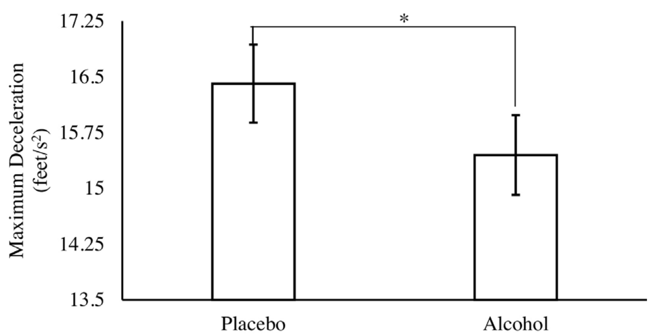

Fig. 5. Main effect of dose on maximum deceleration. Vertical bars indicate the means (± 1SE) of maximum deceleration.

3.4. Acceleration profile

Significant dose x drinking pattern was obtained for mean acceleration (F(1, 149.826) = 15.741, p = 0.000) and maximum acceleration (F(1, 145.485) = 5.807, p = 0.017), (see Figs. 6 and 7). Simple effect analysis showed that non-binge drinkers' mean acceleration and maximum acceleration were both greater under alcohol, compared with the placebo, F(1, 148.273) = 15.701, p = 0.000, F(1, 143.562) = 7.868, p = 0.006, respectively.

3.5. Driving behavior at red lights

3.5.1. Compliance and stop distance

Neither dose, drinking pattern, nor any covariates had a significant effect on the compliance to red lights. Among the cases in which participants who made a full stop at red lights before the lights turned green, a significant main effect of dose was found for drivers' stop distances (F(1,206.750) = 7.729, p = 0.006). Intoxicated drinkers were found to stop closer to the intersection compared with sober drivers and a few intoxicated drivers stopped beyond the stop line and collided with crossing vehicles or pedestrians. In addition, elapsed time had a significant effect on drivers' stop distances (F(1, 101.085) = 4.787, p = 0.031).

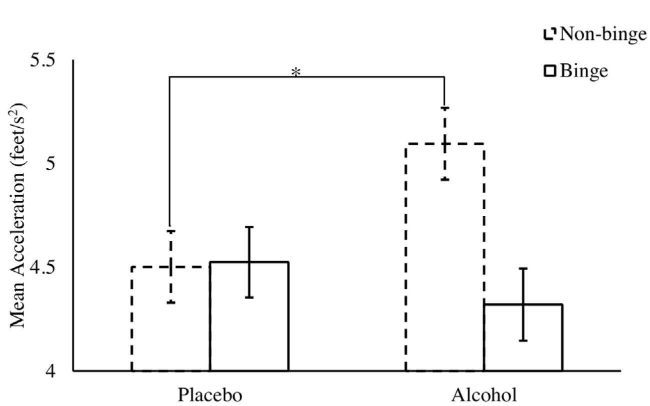

Fig. 6. Effects of dose and drinking pattern on mean acceleration. Vertical bars indicate the means (± 1SE) of the mean acceleration.

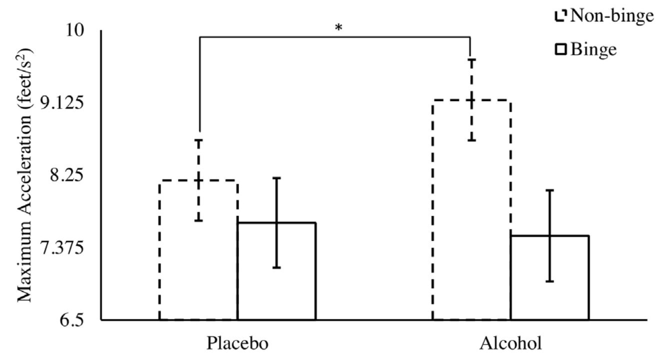

Fig. 7. Effects of dose and drinking pattern on maximum acceleration. Vertical bars indicate the means (± 1SE) of maximum acceleration.

3.5.2. Response time to the yellow lights

Dose had a significant main effect on the response time to the yellow lights (F(1, 245.948) = 6.317, p 0.013), (see Fig. 8). More specifically, intoxicated drivers exhibited longer response times than did sober drivers. Elapsed time was found to be significant on the response time (F(1, 130.755) = 9.115, p 0.003).

3.5.3. Response time to the green lights

Main effects of dose and drinking pattern were not significant on the response time to the green lights. The effects of elapsed time (F(1, 20.872) = 4.822, p = 0.040) and gender (F(1, 20.133) = 11.384, p = 0.003) were both found to be significant on the response time.

3.5.4. Braking profile

Results showed a significant difference between mean deceleration values for sober and intoxicated drivers, with higher mean deceleration for sober drivers (F(1, 195.342) = 10.427, p = 0.001), (see Fig. 9). Similarly, dose had a significant effect on maximum deceleration, with higher maximum deceleration observed among sober drivers compared with intoxicated drivers (F(1, 253.576) = 6.756, p = 0.010), (see Fig. 10). The effects of elapsed time on mean deceleration (F(1, 92.832) = 4.568, p = 0.035), standard deviation of deceleration (F(1, 132.544) = 5.475, p = 0.021), and maximum deceleration (F(1, 143.587) = 6.154, p = 0.014) were also significant. Driving speed when the light turned yellow had significant effects on mean deceleration (F(1, 289.307) = 173.162, p = 0.000), the standard deviation of the deceleration (F(1, 268.804) = 32.884, p = 0.000), and the maximum deceleration (F(1, 283.269) = 37.043, p = 0.000). Also, the subject vehicle's distance to the intersection when the light turned

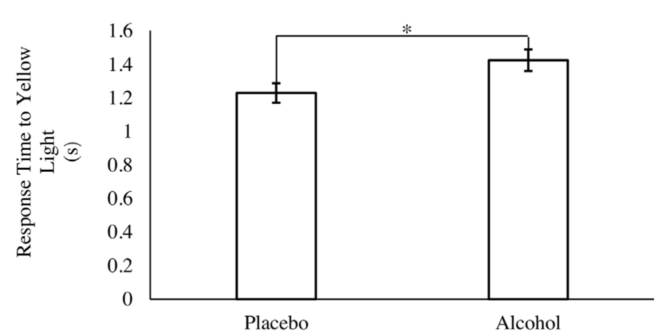

Fig. 8. Effects of dose on driver response time to the yellow light. Vertical bars indicate the means (± 1SE) of response time.

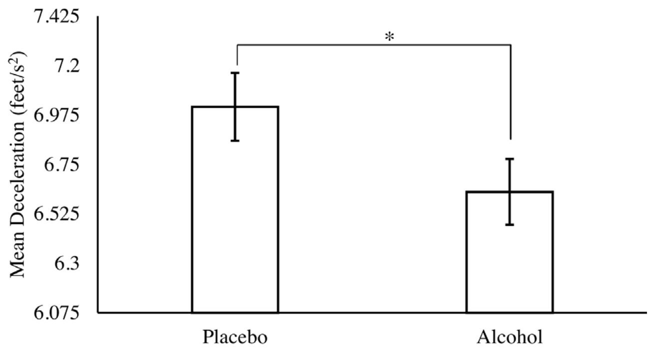

Fig. 9. Effects of dose on mean deceleration at red light. Vertical bars indicate the means (± 1SE) of mean deceleration.

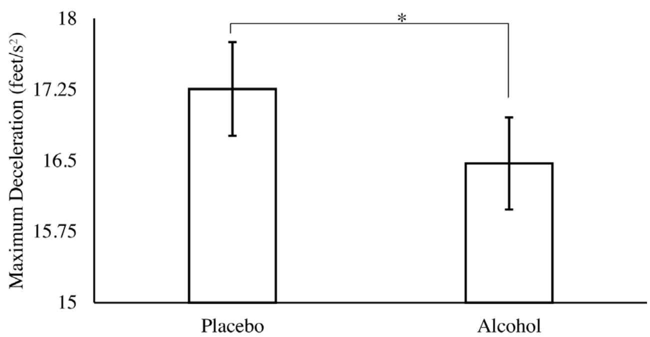

Fig. 10. Effects of dose on maximum deceleration at red light. Vertical bars indicate the means (± 1SE) of maximum deceleration.

yellow had significant effects on mean deceleration ($F(1, 289.537) = 209.531, p = 0.000$), the standard deviation of the deceleration ($F(1, 114.902) = 16.456$, $p = 0.000$), and the maximum deceleration ($F(1, 143.076) = 13.984$, $p = 0.000$). In addition, the elapsed time had significant effect son mean deceleration ($F(1, 92.832) = 4.568$, $p = 0.035$), the standard deviation of the deceleration ($F(1, 132.9544) = 5.475$, $p = 0.021$), and the maximum deceleration ($F(1, 143.587) = 6.154$, $p = 0.014$). Moreover, driving experience's effect on the standard deviation of the deceleration was significant ($F(1, 21.566) = 5.139$, $p = 0.034$).

3.5.5. Acceleration profile

A significant effect of dose was obtained on the standard deviation of acceleration ($F(1, 239.104) = 7.588, p = 0.006$), (see Fig. 11). To be specific, intoxicated drivers exhibited greater standard deviation of acceleration than did sober drivers. In addition, the elapsed time had significant effects on mean acceleration ($F(1, 120.976) = 26.388$, $p = 0.000$) and the maximum deceleration ($F(1, 119.539) = 6.385$, $p = 0.013$). Elapsed time also had significant effects on mean deceleration ($F(1, 120.976) = 26.388$, $p = 0.000$) and maximum deceleration ($F(1, 119.539) = 6.385$, $p = 0.013$).

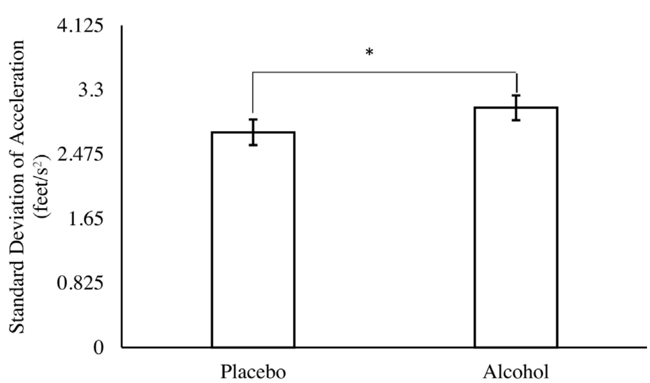

Fig. 11. Effects of dose on standard deviation of acceleration at red light. Vertical bars indicate the means (± 1SE) of standard deviation of acceleration.

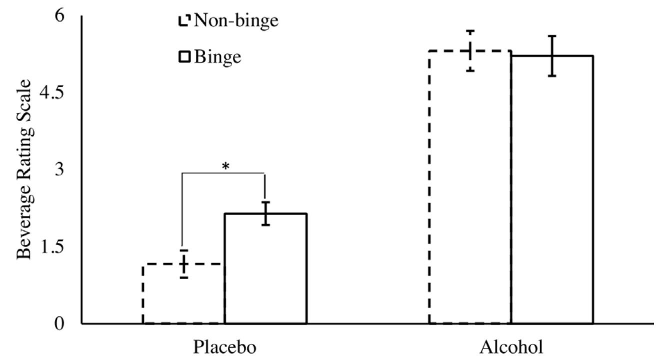

Fig. 12. Effects of dose and drinking pattern on beverage rating scale. Vertical bars indicate the means (± 1SE) of beverage rating.

3.6. Beverage rating scale

A main effect of dose ($F(1, 92.791) = 213.896$, $p = 0.000$) and an interaction effect of dose x drinking pattern ($F(1, 82.752) = 8.476$, $p = 0.005$) were obtained for the beverage ratings. Simple effect analysis suggested that, under the placebo, non-binge drinkers' ratings were significantly higher than that of the binge drinkers ($F(1, 7.411) = 6.772$, $p = 0.013$), (see Fig. 12).

4. Discussions

The present study investigated the effects of alcohol and drinking pattern on driving behavior at stop signs and red lights, which were represented by compliance, stopping duration, stop distance, stopping accuracy, response times, braking profile, and accelerating profile. Existing studies showed that alcohol involvement was reported in 62.3% of all single vehicle crashes in which the driver failed to obey the stop sign, and in 31.9% of the failure to obey the traffic signal (Campbell et al., 2016). Despite the large numbers of crashes at stop signs and traffic signals involving alcohol and their relatively severe nature, drinking and driving behavior at stop signs and traffic signals has not been the subject of much detailed research.

The results showed that alcohol dose and drinking patterns affected general speed and lateral control as well as driving behavior at stop signs and red lights. Alcohol was found to impair driver control of speed and direction. Under alcohol, all participants had greater difficulty in maintaining their lane position and the appropriate speed compared to placebo performance. The impairment of pedal control after alcohol intake was also observed during the accelerating process when the lights turned from red to green. Compared with sober drivers, greater standard deviation of acceleration of intoxicated drivers was observed when the lights turned green. The observed impaired motor control also caused more accidents among intoxicated drivers. In addition, results showed that alcohol prolonged drivers' simple and complex reaction time, which was consistent with (Holloway, 1994). When the lights turned from green to yellow, sober drivers' reaction time was shorter than intoxicated drivers. Lower deceleration was also observed among intoxicated drivers at both stop signs and red lights. Such insufficient deceleration would lead to longer braking distance, which was confirmed by those intoxicated drivers stopping beyond the stop line at both stop signs and red lights. Another possible reason for the lower deceleration and closer stop distance was that alcohol produced visual degradation (Harrison and Fillmore, 2005a) and therefore degraded judgment of distance. The alcohol-induced slower braking and closer stop distance tended to increase the chance of collision with other vehicles as well as with pedestrians at stop sign and red light intersections.

Alcohol appeared to result in more severe impairment among non-binge drinkers. Among non-binge drinkers, more accidents and higher acceleration from stop signs were observed under alcohol, compared with the placebo. Such harder acceleration may suggest that alcohol significantly increase non-binge drinkers' impulsiveness or that alcohol impaired non-binge drinkers' motor control, resulting in drivers pressing down on the gas pedal harder than intended. Such finding was consistent with existing studies that binge drinkers showed less impairment on measures of psychomotor tasks (Goldberg, 2017). However, the impulsivity associated with experienced drinkers (Moselhy et al., 2001) was not observed in the current study. The reason may be that the association between impulsivity and experienced drinkers was observed among drinkers with dysfunction of the frontal lobes due to chronic and excessive alcohol consumption (Moselhy et al., 2001), which was much higher than the alcohol consumption of the participants in the current study.

It was showed that more than 40% of those alcohol-impaired drivers have consumed their last drink on licensed premises (O'Donnell, 1985). Most on-premise establishments are located along urban roads, which drivers use directly after leaving a licensed premises before reaching another destination on an urban road or before merging onto a highway (State Liquor Authority, 2016). The detailed analysis of drinking and driving behavior at stop signs and red lights in this study would be helpful to identify alcohol-impaired drivers at intersections with stop signs or red lights. With pattern recognition algorithms embedded (Chanawangsa et al., 2014a,b), it is possible for the traffic cameras to automatically analyze driving behavior and identify alcohol-impaired drivers at intersections with stop signs or red lights. Then these cameras could send the information of location, vehicle information, direction of driving, etc. to the local police. It would be easier for the police to stop alcohol-impaired drivers on urban roads. As a result, much higher severity of alcohol-impaired driving accident on highways would be prevented.

The relatively small sample size in this study does limit the generalizability of our findings. In the future, a larger sample size that replicates the present study would allow for examination of a variety of individual difference variables that may be of great importance. Future studies also need to examine whether drinking experience and driving experience affect our findings. In addition, whether the extent to which a drinkers believes himself/herself to be intoxicated has an effect on driving behavior at stop signs and red lights was not addressed in the present study. Also, participants could not perceive the real risk of driving in traffic in a simulator. There may be differences between real road driving and simulated driving, which tends to call into question the applicability to the real driving.

In conclusion, the findings of the current study provided some novel insights into drinking patterns and alcohol-impaired driving behavior at stop signs and red lights, which could provide helpful information for interventions to reduce alcohol-related accidents at stop signs and red lights. The results of this study suggested that alcohol impaired driver control of speed and direction, prolonged simple and complex reaction time, and produced and/or visual degradation. Binge and non-binge drinkers differed in their intoxicated driving behavior at stop signs and red lights. Alcohol significantly increased non-binge drinkers' acceleration compared with binge drinkers.

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