A SIMULATION STUDY OF THE EFFECTS OF ALCOHOL ON DRIVING PERFORMANCE IN A CHINESE POPULATION

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ABSTRACT

Driving under the influence of alcohol (DUIA) is a significant factor contributing to road traffic crashes, injuries, and fatalities. Although the effects of alcohol on driving performance are widely acknowledged, studies of the effects of alcohol impairment on driving performance and particularly on the control system of Chinese adults are rare. This study attempts to evaluate the effects of alcohol on the driving performance of Chinese adults using a driving simulator. ***Method:*** A double-blind experimental study was conducted to evaluate the effects of alcohol impairment on the driving performance of 52 Chinese participants using a driving simulator. A series of simulated driving tests covering two driving modules, including emergency braking (EB) and following braking (FB), at 50 km/h and 80 km/h were performed. Linear mixed models were established to evaluate driving performance in terms of braking reaction time (BRT), the standard deviation of lateral position (SD-LANE), and the standard deviation of speed (SD-SPEED). ***Results:*** Driving performance in terms of BRT and SD-LANE was highly correlated with the level of alcohol consumption, with a one-unit increase in breath alcohol concentration (BrAC) degrading BRT and SD-LANE by 0.3% and 0.2%, respectively. Frequent drinkers generally reacted faster in their BRT than less-frequent drinkers and non-drinkers by 10.2% and 30.6%, respectively. Moreover, alcohol impairment had varying effects on certain aspects of the human control system, and automatic action was less likely to be affected than voluntary action from a psychological viewpoint. ***Conclusion:*** The findings should be useful for planning and developing effective measures to combat drink driving in Chinese communities.

Keywords: Traffic safety; drink driving; driving simulator; driving performance, Chinese population.

1 INTRODUCTION

The rapid rise in both motor transport and alcohol consumption has made drink driving a major road safety concern responsible for an increasing number of crashes and injuries in China (Li et al., 2012). It is generally accepted that drink driving significantly increases one's likelihood of engaging in risk-taking behavior. Moreover, the general belief is that the drinking habit of drivers leads to the development of physiological changes that would affect their driving performance. Numerous studies have reported that alcohol-impaired drivers pose a higher crash risk than those who have not consumed alcohol, particularly when the victims are killed or seriously injured (KSI) (Mounce and Pendleton, 1992; Robertson and Drummer, 1994; Tsui et al., 2010; Li et al., 2013a and 2013b). Despite this, as drinking alcoholic beverages has been traditionally accepted in Chinese culture as a part of creating friendships and even successful business, getting drunk is generally not seen as a problem in Chinese communities. Li et al. (2010) revealed that about 35% of Chinese adults abstained from alcohol consumption (55.6% of males and 15.0% of females). Of those who drank, 26.3% of males and 7.8% of females reported doing so frequently, i.e., 5-7 days per week (Li et al., 2010). Moreover, young Chinese adults were found to engage in more risk-taking and risky driving behavior. In particular, 39% of the respondents reported that they had driven after consuming alcohol, and 28% indicated that they may drive after drinking in the future (Chan et al., 2010).

Due to rapid economic development, alcohol consumption is unfortunately increasing faster in China than in other parts of the world (WHO, 2014; Wang et al., 2015). In light of this, it is not surprising that drink driving has become a main cause of road crashes among the Chinese population. In 2011, license suspensions and monetary fines were imposed to combat drink-driving offenses and address the serious problem of drink driving in China. Nevertheless, the reduction in drink-driving-related injuries was less significant than that of overall road injuries (Zhang et al., 2014a). Indeed, researchers have concluded that the random breath test (RBT) is the most effective means of enforcing drink-driving penalties (Erke et al., 2009; Li et al., 2014). Hence, the Government of the People's Republic of China introduced the zero tolerance law in January 2013 to coincide with the application of RBTs. As a result, traffic fatalities caused by drink driving between 2012 and 2013 dropped substantially by 6.81% (from 25.26% to 18.45%) (Wang et al., 2015). Notwithstanding these efforts, the risks of drink-driving fatalities remain considerable and of great concern to Chinese communities.

Until recently, Chinese research related to the driving performance of drivers under the influence of alcohol focused its attention mainly on drink-driving statistics in China (Wang et al., 2015), the prevalence of drink-driving (Yuan et al., 2013; Suo, 2015), or the risks of alcohol impairment (Li et al., 2010; Li et al., 2012; Sun et al., 2014; Zhang et al., 2014a) while ignoring the effects of alcohol on the driving performance of Chinese adults. Indeed, a considerable number of studies have demonstrated that the effects of alcohol degrade many of the important physiological responses involved in driving, decrease judgment and inhibition, impair visual functions, and decrease attention and alertness depending on the amount of alcohol consumed (Schuckit et al., 1997a and 1997b; Fillmore and Vogel-Sprott, 1999 and 2000; Harrison and Fillmore, 2005). These studies have clearly demonstrated that alcohol affects driving performance, which is considered essential to the safe operation of a vehicle. Furthermore, few studies have explored the effects of alcohol impairment on the inhibitory control of different human control systems, either automatically or voluntarily from a psychological viewpoint (Abroms et al., 2006; Cho et al., 2013). In recent years, driving simulators have commonly been used to monitor the effects of alcohol on driving performance in road safety research (Fillmore et al., 2008; Lenne et al., 2010; Wester et al., 2010; Ronen et al., 2010; Harrison and Fillmore, 2011). These simulation studies have generally concluded that variability in speed and lateral position increase as alcohol concentration increases. Simulation studies have also demonstrated that alcohol impairs driving performance by increasing the reaction time of drivers. For example, a simulation study conducted by Christoforou et al. (2013) demonstrated that a 10% increase in alcohol concentration could result in a 2% increase in reaction time. Except for the simulation study conducted by Liu and Ho (2010), who investigated the relationship between alcohol consumption and the performance of drivers in Taiwan, all of these studies have focused on Caucasians in Western countries. The scale of Liu and Ho's (2010) study was relatively small, including only eight licensed drivers as participants. As the physiological responses of Chinese people to alcohol are known to differ from those of Caucasians (Reed et al., 1976), the findings from previous research may not be applicable to a Chinese population.

The current simulation study attempted to evaluate the effects of alcohol on the actual driving performance of Chinese adults using a driving simulator. This paper is organized as follows. Section 2 details the study's materials and methods. Section 3 explains the driving performance data collection process and the formulation of the random-intercept model. Section 4 presents the findings on the differing alcohol-impaired driving performance of Chines adults. Finally, Section 5 concludes the paper by discussing the effects of alcohol on driving performance.

2 MATERIALS AND METHODS

2.1 Participants

To capture the full spectrum of driver types and strive for a balanced distribution of participants in terms of gender and age, 52 Chinese drivers (34 males and 18 females) who had held a valid, full driving license for at least 1 year were recruited through the network of driver associations. The mean age of the participants was 38.2 years (ranging from 21 to 61 years). Every participant was invited to attend two or three experimental sessions, separated by two days or more. Before the experiments began, the participants were required to pass both a health assessment and an Alcohol Use Disorders Identification Test (Saunders et al., 1993), both of which were conducted by a medical doctor. Those who reported previous alcohol or substance abuse or any psychiatric disorder were excluded. Women who were pregnant or breastfeeding (determined by self-report) were not permitted to participate. All of the participants provided informed consent before participating and received HK$50 per hour. Table 1 presents a summary of the participants' statistics.

[Insert Table 1 here]

2.2 Apparatus and materials

Simulated driving tests: Driving performance was measured using a computerized simulated driving test in an enclosed area. A desktop-based XP-300 Driving Simulator (XPI Simulation Ltd., UK) was used in all of the tests. This simulator provided a fully interactive simulated driving environment with three 19-inch LCD monitors, a Logitech G27 steering wheel, and a pedal kit. Figure 1 illustrates the hardware setup. The available driving modules included emergency braking (EB), following braking (FB), the two-second rule, hazard perception, and motorway driving. The simulated driving test recorded the vehicle position, speed, acceleration, time to contact pedals (acceleration and braking), and angle of the steering wheel in a 30-Hz sampling frame.

[Insert Figure 1 here]

Breathalyzer: To measure the BrAC, an Alcotest 9510 evidential breathalyzer (Drager Safety AG & Co., Germany), was used. The Hong Kong Police Force currently uses this breathalyzer in evidential alcohol tests due to its high specificity for ethyl alcohol. It quantifies the alcohol concentration based on two separated breath samples: one measured via infrared red (IR) sensor, the other measured by fuel cell technology (dual sensor technology). The maximum permissible deviation between the readings of two sensors is 5%. In this study, the mean reading of the two sensors was calculated for subsequent analysis.

2.3 Experimental session design

The participants were told that the purpose of the experiment was to study the impairing effects of alcohol on driving performance. They were required to attend two or three experimental sessions separated by two days or more, and given alcohol doses in random amounts (ranging from zero to six standard drinks[1]). The maximum alcohol intake was limited to six standard drinks, which was considered an acceptable and ethical level of alcohol intake (Lenne et al., 2010).

2.3.1 General procedures

Figure 2 illustrates the experimental procedures. Before the experiment, all of the participants were instructed to abstain from food for four hours and from alcohol and sedatives for twenty-four hours. A registered nurse conducted a clinical assessment of the physiological responses of each participant at the start of the experiment. A standard light meal was provided to simulate a normal social drinking occasion and allow for the effect of food on alcohol metabolism. The BrAC was then measured to ensure that every participant was free of alcohol. The participants then completed a 10-minute practice plus a 20-minute simulated driving test before alcohol intake (denoted as "*DT0*"). Approximately 30 minutes after the meal (*time 0*), each participant was asked to consume 500 ml of an alcoholic drink (orange juice mixed with vodka of 40% alcohol by volume) in 15-20 minutes. To decrease the risk of possible bias, a double-blind procedure was used in which neither the participants nor those carrying out the experiments knew the doses of alcohol taken. The BrAC was measured at 10-minute intervals during the

[1] The dose of alcohol was either zero, two, four, or six standard drinks. One standard drink should contain 10 g of pure alcohol and is equivalent to 100 ml of wine with 12% alcohol by volume.

initial rapid absorption phase to ensure that the peak alcohol concentration was measured. The "post-beverage" simulated driving test (denoted as "*DT1*") began about 60 minutes after the start of the alcohol intake (*time 60*) to coincide with the ascending period of the peak alcohol concentration.

Although similar experimental procedures were applied during the elimination phase, BrAC measurements were taken at 60-minute intervals, i.e., at 120, 180, 240, and 300 minutes from the start of the alcohol intake (*time 120*, *180*, *240*, and *300*). Considering that the alcohol-impaired effects would decrease with time after alcohol intake, two further post-beverage simulated driving tests (denoted as "*DT2*" and "*DT3*") were conducted at about 120 and 240 minutes after the start of the alcohol intake (*time 120* and *240*), respectively.

[Insert Figure 2 here]

The participants then rested in the laboratory waiting area until the end of the session. The experiment ended four hours after the alcohol intake or until the BrAC fell to a level of 10 μg/100 ml or below. The protocol of this study was approved by the Institutional Review Board of the University of Hong Kong, Hospital Authority Hong Kong West Cluster.

2.3.2 Driving simulated tests

Practice test: Each session began with a 10-minute practice so that the participants could familiarize themselves with the steering control, accelerator, and brake of the driving simulator. The participants were trained using a free driving module in an urban area, where they could practice speed control, turning, and other general driving techniques without encountering hazards or vehicles on the roads. This was followed by a practical session for each driving module to be taken during the simulated driving test.

Driving simulated test: One baseline (*DT0)* plus three post-beverage (*DT1*, *DT2*, and *DT3)* driving simulated tests were conducted after the alcohol intake. Each test consisted of two modules, including EB and FB, to monitor the impairment of the participants' driving performance. In the EB modules, the participants were required to maintain a constant speed of 50 km/h (or 80 km/h) on a straight section of road and then engage the emergency brake in response to a virtual instruction "STOP" given at random intervals (see Figure 3a). In the FB module, the participants were instructed to maintain their speed and follow at the correct distance behind the car in front at 50 km/h (or 80 km/h) and to brake when the car they were following began to brake (as indicated by its brake light) (see Figure 3b).

[Insert Figures 3a and 3b here]

3 STATISTICAL ANALYSIS

3.1 Data collection

In this simulation study, the level of driving performance was the dependent variable, measured by the braking reaction time (BRT), the standard deviation of lateral position (SD-LANE), and the standard deviation of speed (SD-SPEED). BRT is the time (in seconds) from the appearance of the braking event, T_{Event}, to the brake onset, T_{Brake}. Figure 4 and Equation (1) illustrate the definition of BRT.

[Insert Figure 4 here]

$$\text{BRT} = T_{Brake} - T_{Event} \tag{1}$$

Measurements of the lateral position and vehicle speed within the period between T_{Limit} and $T_{Limit+10}$ were extracted from the dataset to calculate the variation in lateral position and speed (see Figure 5). For a 30-Hz sampling frame, 300 measurements were recorded in a 10-second period. Hence, the SD-LANE and SD-SPEED of each simulated driving test are defined as

$$SD\text{-}LANE = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}}, \text{ for } n = 1, 2, \ldots, 300 \tag{2}$$

$$SD\text{-}SPEED = \sqrt{\frac{\sum_{i=1}^{n}(V_i - V_{Limit})^2}{n-1}}, \text{ for } n = 1, 2, \ldots, 300 \tag{3}$$

where X_i and V_i are the ith measurements of the lateral position and speed, respectively. $\bar{X}$ is the mean of the lateral position and V_{Limit} is the target speed limit of the testing module (either 50 or 80 km/h). The independent variables are the BrAC value; driver drinking habit (non-drinker [never], less-frequent drinker [less than twice per month], or frequent drinker [twice or more per month]); driver age group (young driver [18-24], adult driver [25-54], or older driver [55 or above]); driver gender (female or male); years spent holding a driving license (less than 3 years, 3-10 years, or more than 10 years); occupation as a driver (none, part time, or full time); simulated driving test (DT0, DT1, DT2, or DT3); speed limit (50 or 80 km/h); and driving module (EB or FB) of the simulated driving test.

As previously mentioned, each participant was required to attend two or three experimental sessions. Thirty-one participants attended three sessions, seventeen participants attended two sessions, and the remaining four participants attended only one session. One hundred and thirty-one simulated driving experiments (ninety for males and forty-one for females) were conducted. Invalid measurements due to reported physical illness (e.g., vomiting and headaches) were excluded, leaving 1,933 measurements taken. Table 2 summarizes the characteristics of these measurements.

[Insert Table 2 here]

3.2 Model formulation

To account for the cross-sectional heterogeneity effects of individuals, panel data analysis (Washington et al., 2003) was conducted to identify the possible factors affecting the driving performance of Chinese adults. A linear mixed model was adopted to perform statistical analyses using SPSS 20.0 statistical software to facilitate the model formulation.

In the proposed model, the heterogeneity effects were assumed to be constant for given fixed components and were absorbed by the intercept term as a mean to account for individual heterogeneity. A one-way random-intercept model with the dependent variable y_{it} is specified as

$$y_{it} = \beta_0 + \boldsymbol{X_{it}\beta} + \mu_i + v_{it} \tag{4}$$

where *i* refers to the cross-sectional unit, i.e., the participant in the experiment (i = 1, 2, 3, …, 52), and t refers to the time for the simulated test (t = 1, 2, and/ or 3). μ_i is the unobserved cross-specific effect and v_{it} refers to random disturbances. $\boldsymbol{X_{it}}$ is the vector of the possible contributory fixed variables, including the BrAC value, driver drinking habit, driver age, driver gender, number of years spent holding a driving license, occupation as a driver, simulated driving test, speed limit, and driving module. $\boldsymbol{\beta}$ is the vector of the corresponding coefficient, estimated using the maximum likelihood approach. For the random component, the variances of the random parameters $VAR(u_{it}) = \sigma_\mu{}^2 + \sigma_v{}^2$ are estimated for the purpose of model interpretation.

To assess the goodness-of-fit of the proposed regression model, a likelihood ratio statistic can be calculated with

$$LR = -2(LL(\beta_R) - LL(\beta_U)) \tag{5}$$

where $LL(\beta_R)$ is the restricted log likelihood function and $LL(\beta_U)$ is the unrestricted log likelihood function. Under the null hypothesis that there is no association between the dependent and independent variables, the *LR*-statistic is χ^2 distributed with the degrees of freedom equal to the difference between the numbers of parameters in the restricted and unrestricted models. Thus, a significant *LR*-statistic indicates a good fit for the proposed model.

3.3 Levels of alcohol consumption

To determine the influence of a one-unit increase in BrAC (in μg/100 ml) on driving performance, the odds ratio (OR) of BrAC is calculated as

$$OR = \exp(\beta_j) \tag{6}$$

with 95% confidence intervals (CI) of $\left(\left(\beta_j - 1.96s_{\beta_j}\right), \left(\beta_j + 1.96s_{\beta_j}\right)\right)$, where s_{β_j} is the standard error of the coefficient β.

4 RESULTS AND INTERPRETATION

4.1 Braking reaction time (BRT)

Measurement records were used to establish the regression model when evaluating alcohol-impaired driving performance in an unpredictable emergency situation. Table 3 presents the prediction model results for driving performance in terms of BRT. Based on these results, BrAC (coefficient = 0.0034) contributed to an increase in BRT, and a frequent driver drinking habit (non-drinker: 0.267; less-frequent drinker: 0.097; frequent drinker: control), years spent holding a driving license (3-10 years: 0.146; more than 10 years: control), and full-time occupation as a driver (part-time: 0.188; full-time: control) contributed to a reduction in BRT during the simulated driving test at a 5% level of significance. Furthermore, the type of driving module was a contributing factor to driving performance in terms of BRT. Participants were likely to react faster in the EB module than in the FB module (EB: -0.116; FB: control) at a 5% significance level. The proposed prediction model generally fit well with the data (χ^2 = 288.58).

[Insert Table 3 here]

4.2 Standard deviation of speed (SD-SPEED)

Table 3 also illustrates the model results for driving performance in terms of SD-SPEED. Alcohol-related factors had no significant influence. In contrast, the demographic characteristics of the individual participants including old (young driver: -1.220; older driver: control) and female (female: 0.700; male: control) drivers contributed to an increase in speed variation. Moreover, speed limit was one of the factors contributing to the driving speed variation, where SD-SPEED decreased as the driving speed increased (50 km/h: 0.830; 80 km/h: control). Similar to the case of BRT, participants were likely to perform better in the EB module than in the FB module (EB: -0.975; FB: control), as shown in the SD-SPEED prediction model at a 5% significance level. The proposed prediction model generally fit well with the data (χ^2 = 371.01).

4.3 Standard deviation of lateral position (SD-LANE)

BrAC (coefficient = 0.0024) and not driver drinking habit was the major factor contributing to an increase of SD-LANE at a 5% significance level. In addition, older drivers (young drivers: -0.142; adult drivers: -0.122; older drivers: control) contributed to an increase in SD-LANE. However, full-time drivers (part time: 0.169; full time: control) and a higher speed limit (50 km/h: -0.027; 80 km/h: control) contributed to a reduction in SD-LANE during the simulated driving test, both at a 5% level of significance. No correlation was found between SD-LANE, driver gender, and years spent holding a driving license. Unlike BRT and SD-SPEED, different driving modules were not likely to have an influence on SD-LANE. The proposed prediction model fit well with the experimental data (χ^2 = 14.741).

To conclude, alcohol-impaired effects on BRT and SD-LANE, but not on SD-SPEED, were observed during the simulated driving tests. Furthermore, the time the simulated driving tests took had no significant effect on the driving performance of the participants in any of the models.

4.4 Automatic vs. voluntary action

In this simulation study, two simulated driving modules, including EB and FB, were used to measure the alcohol-impaired driving performance of the participants. The EB module involved a type of automatic control that allowed the participants to shift their attention automatically in response to a sudden "STOP" signal. In contrast, the FB module involved voluntary control, as from a psychological viewpoint the participants shifted their attention voluntarily. By comparing the participants' driving performance in terms of BRT between the EB and FB modules, it was possible to investigate any difference in alcohol-impaired effects between the automatic and voluntary control groups.

As shown in Table 3, alcohol-impaired driving performance in terms of BRT was highly correlated with the simulated driving modules (EB: -0.116; FB: control) at a 5% significance level, meaning that both the automatic and voluntary control groups were likely to be affected by alcohol. However, the participants were likely to react faster in the EB module than in the FB module by 11% (OR = 0.890; 0.95CI = 0.878, 0.903). The effects of alcohol impairment on aspects of the control system therefore varied, with the automatic control group less likely to be affected than the voluntary control group.

5 DISCUSSION

Over the decades, many driving simulation studies have been conducted to examine alcohol-impaired driving performance in Western countries (see Table 4). Researchers have generally agreed that after alcohol consumption the human brain requires a longer time to perceive visual stimuli and process information and the transmission of signals to the muscles is delayed (McMillen and Well-Parker, 1987; Fillmore and Vogel-Sprott, 2000). Alcohol concentration can thus affect various aspects of physiological driving performance, mainly in terms of driving reaction time, lane, and speed variations.

[Insert Table 4 here]

For example, in an assessment made by Fillmore et al. (2008), the deviation of lateral position increased by 0.6% for a one-unit (in μg/100 ml) increase in BrAC.[2] Weafer et al. (2008) similarly found that a one-unit increase in BrAC could increase the deviation of lateral position by 0.3%. Christoforou et al. (2013) evaluated the relationship between the level of BrAC and driving reaction time and found that a 10% increase in BrAC caused a 2% increase in reaction time. In terms of speed variation, numerous researchers have suggested that alcohol consumption should have no significant influence on driving speed (Weafer et al., 2008). However, some have argued that alcohol can affect driving speed and hence the deviation of speed while driving. For example, Lenne et al. (2010) compared the driving performance of 47 drivers under the influence of low and high alcohol doses (19 and 28 μg/100 ml, respectively). They found that the standard deviation of speed increased with low but not high alcohol dosages. In terms of the Chinese population, Liu and Ho (2010) demonstrated that the variance in longitudinal speed and reaction

[2] The value of BAC (in g/kg) given in the original research article was converted to BrAC (μg/100 ml) in a blood-to-breath ratio of 2,300:1 in this study.

time increased with alcohol consumption. Nevertheless, the scale of their research was relatively small and may be inadequate to reflect the alcohol-impaired drink-driving performance of the Chinese population. The driving simulation experiment conducted in the current study provided more information in this area. Indeed, consistent with many previous studies conducted in Western countries, this simulation study found that driving performance in terms of BRT (which could be related to the reaction time of drivers) and SD-LANE (i.e., the standard deviation of lane position) were highly correlated with the level of alcohol consumption. A one-unit increase in BrAC increased BRT by 0.3% (OR = 1.003, 0.95CI = [1.002, 1.004]) and SD-LANE by 0.2% (OR = 1.002, 0.95CI = [1.001, 1.003]). In our developed model for driving performance in terms of SD-SPEED (which could be related to speed variations), alcohol consumption had no apparent significant effect on speed variation.

Over the years, researchers have argued that separate neural systems exist to control the automatic and voluntary actions (Corbetta and Shulman, 2002; Gazzaniga et al., 2002). Although numerous studies have been conducted to investigate the impairment effects of alcohol on attention (Fillmore and Vogel-Sprott, 1999 and 2000; Harrison and Fillmore, 2005), its effects on the two control systems are not well understood. In light of this, Abroms et al. (2006) conducted research into the effects of alcohol impairment on the inhibitory control of the different control systems. The findings demonstrated that vehicle control depends more on voluntary action than automatic action. More recently, research by Cho et al. (2013) also examined the voluntary action of drivers, and whether it is impaired and more likely to cause crashes and injuries if so. However, the alcohol-impairment effects on automatic actions were not mentioned in their study, and we have found few studies that review alcohol-impaired driving performance due to the difference between voluntary and automatic actions. The results of this simulation study demonstrated that the degree of alcohol impairment of aspects of the human control system varies, and automatic action is less likely to be affected than voluntary action. It is commonly believed that slow response to road hazards is the main cause of alcohol-related road crashes. In fact, the influences of alcohol on basic vehicle control skills, such as acceleration, deceleration, and changing lanes, may be of a greater safety concern to the driver himself.

The results of this study also support the general belief that frequent drinking leads to the development of physiological changes that increase one's alcohol tolerance, minimizing the effects of alcohol consumption on the driving performance of frequent drinkers (Schechtman et al. 1999). Table 3 indicates that frequent drinkers generally reacted faster than less-frequent drinkers and non-drinkers in their BRT. Comparing the alcohol-influenced driving performance of frequent drinkers and other drivers, the BRT of less-frequent drinkers was slower than that of frequent drinkers by 10.2% (OR = 1.102, 0.95CI = [1.024, 1.182]). Alcohol-influenced driving performance was even worse for non-drinkers, whose BRT increased by 30.6% (OR = 1.306, 0.95CI = [1.133, 1.505]). However, the drinking habits of drivers were unlikely to have different effects on vehicle control, including driving performance in terms of SD-SPEED and SD-LANE. Although frequent drinkers seem to exhibit better driving performance than less-frequent drinkers and non-drinkers, this should not be an excuse to drink alcohol, as frequent or binge drinking has proved to have adverse effects on health and risk-taking behavior (Schechtman et al., 1999; Clark et al., 2001, LaBrie et al., 2011). Although driving performance is significantly degraded for non-drinkers, these drivers are not likely to engage in drink driving. More efforts to combat drink driving effectively should focus on drinking drivers and especially less-frequent drinkers, who present a higher accident risk than frequent drinkers and other road users. For example, ignition interlock devices should be implemented. These devices have been widely promoted in many Western countries but are considered as a new and emerging technology for the Chinese population.

The findings of this study may be useful for police and policymakers to estimate the influence of alcohol on different aspects of driving performance. For example, the Hong Kong SAR Government imposed a three-tier sliding scale penalty system for drink-driving offenses that applied different penalties to BrAC levels exceeding 22, 35, and 66 μg/100 ml, respectively. Assuming a normal BRT of 2.5 seconds and based on the current results of a 0.3% increase in braking reaction time per unit increase in BrAC, the stopping distances increase by 4, 6, and 11 m for BrAC of 22, 35, and 66 μg/100 ml of breath, respectively, at a vehicular speed of 80 km/h. The general practice of the two-second rule may be inadequate to provide a safe following distance for drivers under the influence of alcohol and thereby have no effect on the frequency of rear-end collisions. In this study, variations in lateral position were correlated with alcohol concentration levels. Furthermore, the presence of a curve in the association between lateral stability and alcohol level indicated the possibility of interaction, and impaired drivers tended to travel on one particular side of the lane (Zhang et al., 2014b). Therefore, lateral stability may be an effective performance indicator for the detection of drink-driving. This finding has implications for the planning and implementation of enforcement against drink-driving.

6 CONCLUSION

A series of driving simulated tests was conducted to evaluate the driving performance of Chinese adults under the influence of alcohol. Each simulated test consisted of two driving modules, including EB and FB, to monitor the impairment of the driving performance of 52 participants. Their driving performance was measured in terms of their BRT, SD-LANE, and SD-SPEED, and linear mixed models were established to identify the contributing alcohol-related and other confounding factors. Similar to the findings of many studies conducted in Western countries, driving performance in terms of the BRT and SD-LANE of Chinese adults was highly correlated with their level of alcohol consumption. Consistent with previous studies, the effects of alcohol impairment on certain aspects of the human attentional control system varied, and automatic action was less likely to be affected than voluntary action from a psychological viewpoint. It is commonly believed that slow response to road hazards is the main cause of alcohol-related road crashes. In fact, this study demonstrated that the influence of alcohol on basic vehicle control skills, such as acceleration, deceleration, and lane changing, may be a greater safety concern for drivers.

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Table 1 Summary statistics for the participants (Sample size = 52)

Factor	Attribute	Frequency	Percent (%)
Age	Young driver (18-24)	8	15.4
	Adult driver (25-54)	40	76.9
	Old driver (55 or above)	4	7.7
Gender	Female	18	34.6
	Male	34	65.4
Years spent holding a driving license	Less than 3 years	9	17.3
	3-10 years	13	25.0
	More than 10 years	30	57.7
Occupation as driver	Full time	3	5.8
	Part time	8	15.4
	No	41	78.8
Drinking habit	Non-drinker (never)	3	5.8
	Less-frequent drinker (less than twice per month)	30	57.7
	Frequent drinker (twice or more per month)	19	36.5

Table 2 Summary statistics for the simulated driving test (Sample size = 1,933)

Factor (Range)	Mean (SD)								
	Overall	Simulated driving test				Speed limit		Module	
		DT0	DT1	DT2	DT3	50 km/h	80 km/h	EB	FB
Observation	1,933	480	487	485	481	947	986	964	969
BRT (0.48, 2.1)	0.75 (0.21)	0.70 (0.16)	0.79 (0.25)	0.77 (0.22)	0.74 (0.19)	0.76 (0.29)	0.75 (0.21)	0.69 (0.14)	0.81 (0.25)
SD-SPEED (0.08, 17.5)	2.41 (1.75)	2.45 (1.70)	2.41 (1.83)	2.41 (1.63)	2.38 (1.83)	2.83 (1.63)	2.01 (1.77)	1.93 (1.38)	2.89 (1.94)
SD-LANE (0.003, 2.72)	0.19 (0.20)	0.17 (0.16)	0.21 (0.21)	0.20 (0.24)	0.18 (0.18)	0.18 (0.18)	0.21 (0.22)	0.19 (0.19)	0.19 (0.21)
BrAC (0, 68.75)	11.30 (10.64)	1.50 (0.25)	20.70 (11.23)	14.57 (9.19)	8.27 (6.08)	11.40 (10.68)	11.30 (10.64)	11.30 (10.65)	11.30 (10.63)

Notes: BRT: braking reaction time;
SD-SPEED: standard derivation of speed;
SD-LANE: standard derivation of lane position;
BrAC: breath alcohol concentration;
SD: standard deviation.

Table 3 Parameter estimates of the linear mixed model for the different aspects of driving performance

	BRT		SD-**SPEED**		SD-**LANE**	
	Coefficient	**(*t*-statistic)**	**Coefficient**	**(*t*-statistic)**	**Coefficient**	**(*t*-statistic)**
Number of observations	1,933		1,933		1,933	
Fixed variables						
Constant	0.560	(8.414)**	3.374	(6.428)**	0.107	(1.605)
(a) Alcohol-related factors						
BrAC	0.0034	(6.535)**	0.0064	(1.436)	0.0024	(4.595)**
Drinking habit						
- Non-drinker	0.267	(3.792)**	0.156	(0.282)	0.122	(1.730)
- Less-frequent drinker	0.097	(2.777)**	-0.463	(-1.684)	0.009	(0.261)
- Frequent drinker	(Control)		(Control)		(Control)	
(b) Confounding factors						
Age						
- Young driver	-0.093	(-1.322)	-1.220	(-2.203)*	-0.151	(-2.144)*
- Adult driver	-0.080	(-1.952)	-0.632	(-1.959)	-0.143	(-3.478)**
- Older driver	(Control)		(Control)		(Control)	
Gender						
- Female	0.056	(1.700)	0.700	(2.673)*	0.052	(1.564)
- Male	(Control)		(Control)		(Control)	
Years spent holding a driving license						
- Less than 3 years	0.121	(1.909)	-0.039	(-0.078)	0.057	(0.890)
- 3-10 years	0.146	(3.285)**	0.498	(1.424)	0.045	(1.008)
- More than 10 years	(Control)		(Control)		(Control)	
Occupation as a driver						
- No	0..120	(1.710)	-0.550	(-0.994)	0.105	(4.481)
- Part time	0.188	(2.496)*	-0.657	(-1.106)	0.169	(2.231)*
- Full time	(Control)		(Control)		(Control)	
Simulated driving test						
- DT0	-0.021	(-1.948)	0.110	(1.170)	0.008	(0.727)
- DT1	0.007	(0.571)	-0.064	(-0.614)	0.004	(0.292)

- DT2	-0.003	(-0.272)	-0.034	(-0.363)	0.009	(0.872)
- DT3	(Control)					
Speed limit						
- 50	0.012	(1.668)	0.830	(13.240)**	-0.027	(-3.656)**
- 80	(Control)		(Control)		(Control)	
Scenario						
- EB	-0.116	(-15.903)**	-0.975	(-15.574)**	-0.002	(-0.296)
- FB	(Control)		(Control)		(Control)	
Random variable						
Var(Intercept)[#]	0.010	(4.219)**	0.596	(4.219)**	0.010	(4.272)**
Goodness-of-fit						
Restricted log likelihood	537.43		-3,615.96		686.40	
Unrestricted log likelihood	681.72		-3,430.95		679.03	
Likelihood ratio test	288.58**		371.01**		14.741**	

[*] $p < 0.05$; [**] $p < 0.01$; BrAC: breath alcohol concentration.
[#] Variance of the random variables.

Table 4 Simulation driving experiments on alcohol-impaired driving performance

Ref.	Country	Drinking category	Simple size	Descriptions
Burian et al., 2002	USA	0.3, 0.5, and 0.8 g/kg	13	- No effect on *speed.*
Harrison et al., 2005	USA	0.65 g/kg	28	- Increase in *lane variation*.
Leung and Starmer, 2005	Australia	0.7 g/kg (male); 0.6 g/kg (female)	32	- Decrease in *detection times*. - No effect on *overtaking behavior*.
Fillmore et al., 2008	USA	0.65 g/kg	14	- Increase in *speed*, *lateral position*, and *lane variation.* - No effect on *reaction time*.
Weafer et al., 2008	USA	0.0, 0.45, and 0.65 g/kg	24	- Increase in *speed variation* and *lane position*.
Ronen et al., 2010	Israel	0.05% BAC	12	- Increase in *driving speed* and *steering wheel deviation*. - Decrease in *lane position variation*. - No effect on *speed variation*.
Wester et al., 2010	The Netherlands	0.00%, 0.02%, 0.05%, 0.08%, and 0.10% BAC	32	- Increase in *reaction time*.
Lenne et al., 2010	Australia	0.4 and 0.6 g/kg	47	- Increase in *speed* and *lateral position variation*.
Liu and Ho, 2010	Taiwan	0.0%, 0.05%, 0.08% and 0.10% BAC	8	- Increase in *variance in longitudinal speed* and *reaction time*.
Harrison and Fillmore, 2011	USA	0.65 g/kg	40	- Increase in *standard deviation of lane position*. - No effect on *driving speed*.
Christoforou et al., 2013	Greece	Moderate	49	- Increase in *reaction time*.
Helland et al., 2013	Norway	0.0, 0.7 and 1.05 g/kg	20	- Increase in *standard deviation of lane position*.
Charlton and Starkey, 2015	New Zealand	Moderate, High	44	- Significant effect on *steering performance* and *mean speed*.
Our study	Hong Kong	Low, Moderate	52	- Increase in *braking reaction time* and *standard deviation of lane position*. - No effect on *standard deviation of speed*.

Notes: Light – an alcohol dose of less than 0.3 g/kg.
Medium – an alcohol dose of 0.6 g/kg (female) and 0.75 g/kg (male) or a target of 0.05 BAC.
High – an alcohol dose of ≥0.75 g/kg (female) and ≥1.0 g/kg (male) or a target of ≥0.08 BAC.

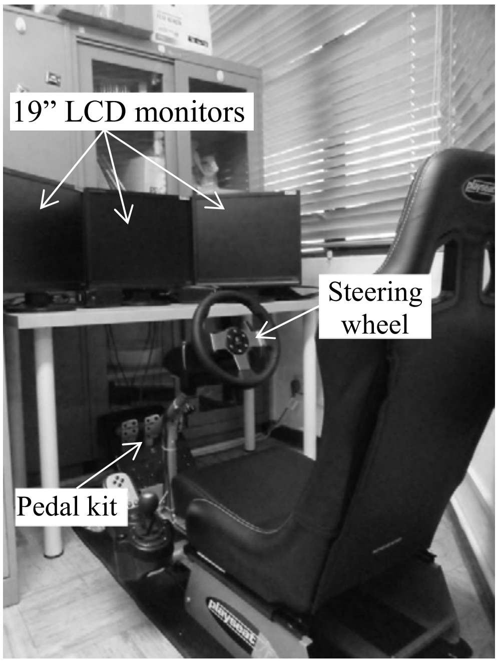

Figure 1 Hardware set up of the driving simulator

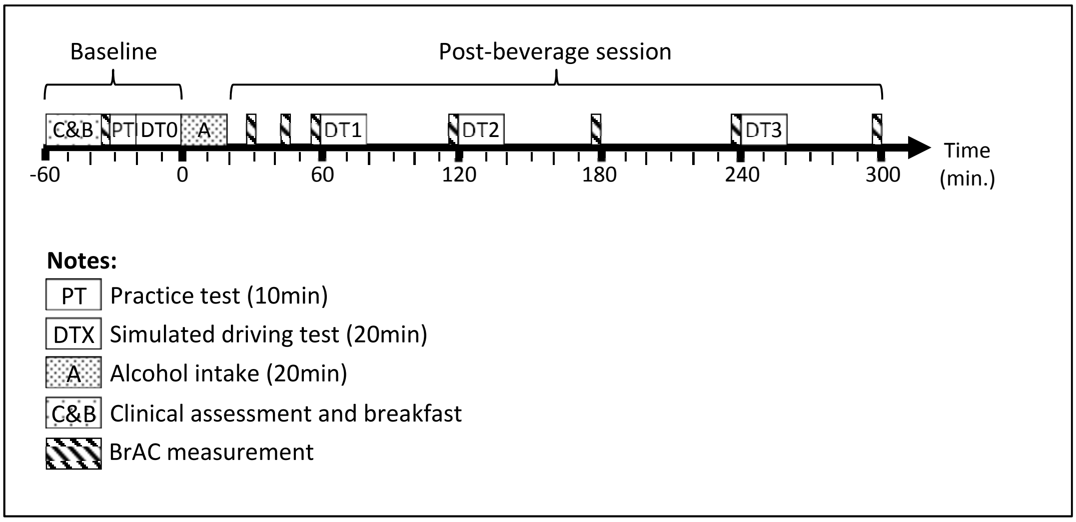

Figure 2 General experimental procedures

Figure 3a Emergency braking module at 50 km/h in the simulated driving test


Figure 3b Following braking module at 80 km/h in the simulated driving test

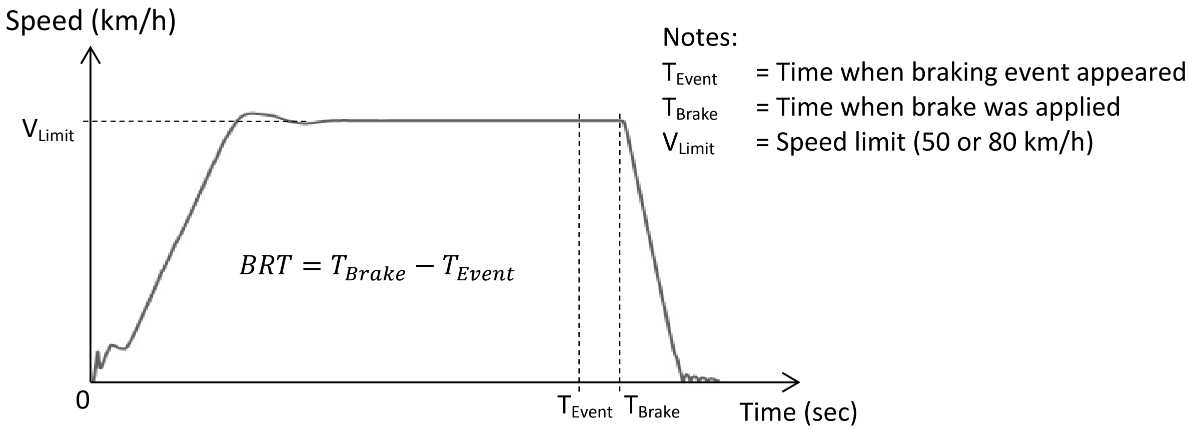

Figure 4 Definition of braking reaction time

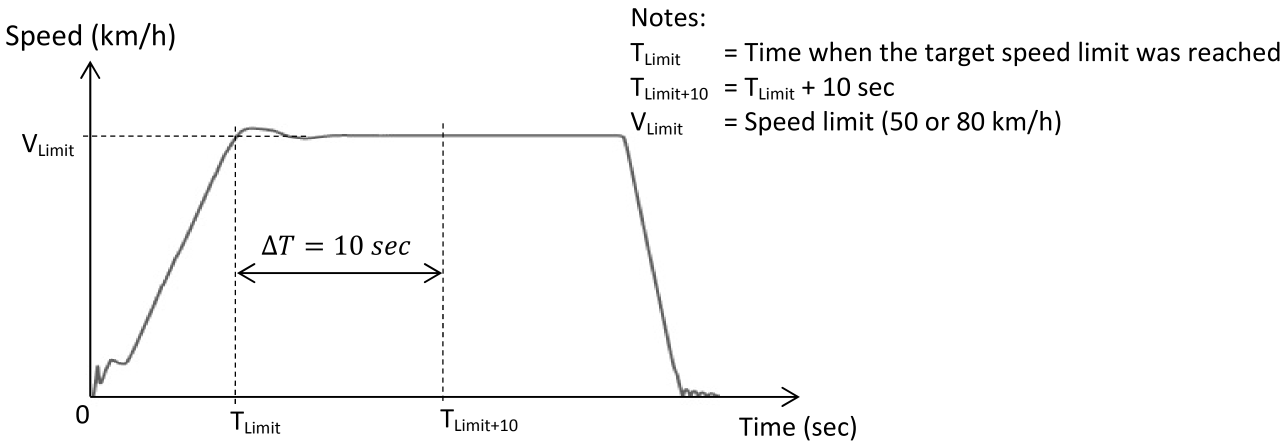

Figure 5 Measurements of lateral position and speed