Accident Analysis and Prevention 72 (2014) 401–410

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Effect of different breath alcohol concentrations on driving performance in horizontal curves

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ARTICLE INFO

Article history:
Received 26 January 2014
Received in revised form 22 July 2014
Accepted 29 July 2014
Available online 21 August 2014

Keywords:
Breath alcohol concentration
Drinking and driving
Curves
Driving performance
Driving simulator

ABSTRACT

Driving under the influence of alcohol on curved roadway segments has a higher risk than driving on straight segments. To explore the effect of different breath alcohol concentration (BrAC) levels on driving performance in roadway curves, a driving simulation experiment was designed to collect 25 participants' driving performance parameters (i.e., speed and lane position) under the influence of 4 BrAC levels (0.00%, 0.03%, 0.06% and 0.09%) on 6 types of roadway curves (3 radii × 2 turning directions). Driving performance data for 22 participants were collected successfully. Then the average and standard deviation of the two parameters were analyzed, considering the entire curve and different sections of the curve, respectively.

The results show that the speed throughout curves is higher when drinking and driving than during sober driving. The significant interaction between alcohol and radius exists in the middle and tangent segments after a curve exit, indicating that a small radius can reduce speed at high BrAC levels. The significant impairment of alcohol on the stability of speed occurs mainly in the curve section between the point of curve (PC) and point of tangent (PT), with no impairment noted in tangent sections. The stability of speed is significantly worsened at higher BrAC levels. Alcohol and radius have interactive effects on the standard deviation of speed in the entry segment of curves, indicating that the small radius amplifies the instability of speed at high BrAC levels. For lateral movement, drivers tend to travel on the right side of the lane when drinking and driving, mainly in the approach and middle segments of curves. Higher BrAC levels worsen the stability of lateral movement in every segment of the curve, regardless of its radius and turning direction. The results are expected to provide reference for detecting the drinking and driving state.

1. Introduction

It is well-known that driving under the influence of alcohol has a high probability of causing traffic crashes. Even with a small amount of alcohol consumption, drivers are twice as likely as sober drivers to be involved in traffic crashes (Le et al., 1999). In Australia, a blood alcohol concentration (BAC) level of 0.05% has been found in about 30% of all drivers fatally injured in crashes (Drummer et al., 2003). Drinking and driving is thought to be responsible for about 20% of all road fatalities in Europe each year (Sørensen and Assum, 2008). In the U.S., crashes due to alcohol-impaired driving contribute to approximately 31% of all traffic fatalities (Lee et al., 2010). In Canada in 2003, 38.3% of fatal driver injuries were alcohol-related (Traffic Injury Research Foundation of Canada, 2005). Li et al. (2012) revealed that about 34.1% of road crashes in China were related to alcohol consumption.

For years, many countries have been working on solutions to drinking and driving, including publicity and education as well as tough drunk-driving laws. Laws have been enacted to prohibit driving after drinking and to impose severe penalties on violators (Liu and Ho, 2010). The legal limits for BAC, varying among countries, are between 0.01% and 0.08%. For example, the limit is 0.02% in Sweden; 0.05% in Israel, Korea and Australia; 0.08% in Canada, England, Mexico and the United States. In China, driving with a BAC level between 0.02% and 0.08% is defined as drink-driving and the driver is penalized. Moreover, driving with a BAC higher than 0.08% is considered drunk-driving and the penalty is even more severe.

Even so, it is difficult to completely eliminate drinking and driving. Not only must strict laws be enacted, but drivers' drinking and driving behavior must be detected immediately. Considering that driving performance is obviously related to driving behavior,

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http://dx.doi.org/10.1016/j.aap.2014.07.032
0001-4575/

detection based on driving performance is just one effective approach. It is also the long-term objective of our research. But first of all, it is important to determine the characteristics of driving performance affected by drinking and driving. The correlation between different BAC levels and characteristics of driving performance is fundamental to detecting drinking and driving. Numerous research studies have explored the effects of drinking and driving on driving performance. On the one hand, the characteristics of the effects of drinking and driving can help to distinguish the drinking and driving state; on the other hand, the characteristics can contribute to the creation of countermeasures to drinking and driving. Some researchers have proven that alcohol does cause a decline in driving performance. A review of literature conducted by Moskowitz and Fiorentino (2000) showed that drivers' steering and brake control ability could be impaired by alcohol at very low doses. Linnoila et al. (1980) indicated that a driver's ability to operate a vehicle was affected at a BAC level of 0.035%. Alcohol also decreases hand steadiness (Laberg and Loberg, 1989) and operating accuracy at a BAC level of 0.06% (Smiley, 1986). Some research studies have found that alcohol impairs behaviors such as steering and braking at BACs ranging from 0.05% to 0.10% (Harrison and Fillmore, 2005; Harrison et al., 2007; Liguori et al., 1999). Fillmore et al. (2008) expressed that alcohol significantly impaired driving performance, which included deviation of lane position, line crossings, steering rate, and driving speed. Chamberlain and Solomon (2002) concluded that alcohol consumption negatively affects steering wheel control and braking behavior. In other words, there is unequivocal evidence that alcohol significantly impairs driving performance. Because of the risks of drinking and driving, most of the experiments were performed based on a driving simulator. The validity of using the driving simulator for studies has been verified in depth by Bella (2005, 2008).

Although there has been ample research about the relationship between alcohol and driving performance, few studies explain the relationship considering roadway geometry. Some researchers have stated that driving in curves is less safe than driving on straight segments. Leung and Starmer (2005) indicated that reaction time was significantly longer with alcohol consumption and lower speeds of approaching vehicles, particularly in curved sections of roads. Chen et al. (2007) explained that the crash risk in road curves is influenced by the road design, such as the degree of curvature, length of curve and lane width, and that alcohol impairment can increase drivers' exposure to crash risk when negotiating a road curve. Zegeer et al. (1992) demonstrated that the crash rates in horizontal curves are about 1.5–4 times higher than on straight segments on rural 2-lane highways. Moreover, curve-related crashes are more severe than those on straight segments (Glennon et al., 1985). The higher risk in curves than on straight segments indicates different needs, in terms of driving ability and driving performance, on different road segments. As alcohol impairs driving ability, it is believable that driving under the influence of alcohol in curves carries a greater risk than driving on straight segments. We can also deduce that the effects of alcohol on driving performance differ in different roadway geometries. The accurate detection of drinking and driving based on driving performance should not ignore roadway alignment. Therefore, it is necessary to verify the effects considering roadway segments with different alignments. Curves were the focus of this study.

According to the research mentioned above, in order to study the detection method of drinking and driving, in this specific study we mainly tried to acquire the characteristic effects of alcohol on driving performance on different curves. Furthermore, we also tried to get the detailed characteristics in different positions of curves to find the key position. Experiments were designed based on a driving simulator; this paper assessed the influence of different BrACs on six types of horizontal curves (three different radii × two turning directions). Longitudinal speed and lateral lane position were the dependent variables. The means and standard deviations of these variables were the indicators for drivers' performance measures. In the analysis, we first studied the characteristic effects of alcohol on the indicators in the entire curve. Then the detailed effects in different curve positions were analyzed. To summarize, the objectives of this study were as follows: (1) to explore the effect of different BrAC levels on driving performance, (2) to study the characteristic effects in different curves, and (3) to analyze the characteristic effects in different curve positions. Through the research, it is expected that the results can provide references for detection of the drinking and driving state.

2. Materials and method

2.1. Participants

It has been found that for the same level of BAC, young drivers have a higher relative crash risk than older drivers (Mayhew et al., 1986; Zador, 1991). Thus, studying young drivers who drink and drive is crucial to improving traffic safety (Woodall et al., 2004). Furthermore, Nagoshi et al. (1991) indicated that male drivers affected by drinking and driving were considered more impulsive and sensation-seeking than female drivers. An Australian study also indicates that young male drivers are more likely to have a positive BAC than females for the same age groups (Holubowycz et al., 1994). Therefore, 25 healthy, young male subjects were recruited to participate in the research. The average age was 25 (standard deviation = 4.1, range = 20–35 years). All participants have possessed a valid driver's license for more than 3 years (average = 3.6). On average, each participant drives a vehicle more than 1 h each day. The recruiting criteria included a regular circadian rhythm and no drug use. Participants' sleep rhythm and drug use were investigated during recruitment. During every simulated driving experiment, the participants were also investigated through a questionnaire whether they had any drug use. Only drivers with no drug use were allowed to perform the experiment. All drivers had the experience of drinking enough alcohol producing a peak BrAC level of 0.1%. Before they were recruited, participants were required to pass a test in which their BrAC reached this level and they could perform tasks according to our requirements. All participants agreed and signed an informed consent before participating in the study, and they were paid for their participation in the experiment.

2.2. Equipment

In order to collect driving behavior data without confounding factors on participants and compromising driver safety, a driving simulator was used in this experiment. Driving simulations were performed with the Auto-Sim driving simulator system. The simulator required driving on the left side of the vehicle. It consists of six networked computers and a few operation hardware interfaces, including steering systems, three pedals and a manual gearshift. The road scenario was projected onto three large screens in front, providing a 130-degree field of view, with two side mirrors, and one rear view mirror showing a very realistic view to the rear. The simulator allowed the recording of the intensity of the driver's actions on three pedals (brake, throttle and clutch), steering wheel angle, and gear status. Additionally, the simulator provided numerous other parameters that describe the vehicle's traveling conditions, including speed, lane position, displacement and acceleration. The sampling frequency of the driving simulator in this experiment was 30 Hz.

Another apparatus was a blowing-type BrAC detector, which was used in the experiment to test drivers' BrAC levels. The detector is identical to the one used by traffic police in Beijing. The