



Laboratory analysis of driving behavior and self-perceived physiological impairment at 0.03%, 0.05% and 0.08% blood alcohol concentrations



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ABSTRACT

Background: Alcohol-impaired driving is a critical factor leading to traffic crashes worldwide. Since decades, researchers from the developed nations have been investigating the effects of alcohol intoxication on their drivers. However, alcohol effects on the drivers of developing countries remain understudied. The extent of alcohol impairment may vary among the drivers of developed and developing nations due to the differences in drivers' physiology, driving conditions, drinking habits, policy enforcement and driving attitude.

Methods: This study examined the effects of different Blood Alcohol Concentration (BAC) levels (0%, 0.03%, 0.05%, and 0.08%) on 75 licensed Indian drivers (56 males and 19 females) with the help of a fixed-base driving simulator. Subjects completed driving simulations for all the BAC levels in a driving environment representing heterogeneous traffic conditions. Performance measures included longitudinal and lateral driving control indicators (obtained from simulator) along with the self-reported physiological changes in the drivers (obtained from questionnaire) with varying BAC levels.

Results: Mean speed was the only performance measure significantly affected at 0.03% BAC. At 0.05% BAC, mean speed and mean steering wheel angle were the two significantly impaired measures. At 0.08% BAC, all the driving performance measures showed significant impairment except steering wheel angle variability. Physiological characteristics of drivers deteriorated with rising BAC levels.

Conclusions: Alcohol significantly impaired the physiology of Indian drivers resulting in impairment in their driving performance. Mean speed was the only performance measure significantly affected by all the BAC levels, making it a suitable parameter to detect the alcohol-impaired state of the drivers.

1. Introduction

Drunk driving is positively correlated with crash risk which increases exponentially beyond 0.04% to 0.05% BAC (Blomberg et al., 2009). To regulate the alcohol-related crashes, various countries have implemented maximum Blood Alcohol Concentration (BAC) limits for driving. For instance, the BAC limit is 0.08% in the United States of America (USA) and the United Kingdom (UK); 0.05% in Australia and South Africa and 0.03% in Chile, Japan, India and Russia.

Alcohol consumption in India is continuously increasing every year (Caetano and Laranjeira, 2006). Driving under the influence of alcohol resulted in 14,071 road traffic crashes in India in 2017 out of which 4776 were fatalities (Ministry of Road Transport and Highways, 2017). Alcohol not only impairs the processes critical to safe driving such as reaction time (Yadav and Velaga, 2019a) and vision (Alford et al., 2012), but also impairs the judgement ability of the driver (Zhao et al., 2014) and increases the tendency of committing errors while driving

(Friedman et al., 2011). Due to this reason, it is often linked to high risk driver behaviors like speeding and sudden lane changing (Christoforou et al., 2012). Alcohol influences the decision making of an individual (Allen et al., 2009) and results in cognitive impairment (Brumbach et al., 2007). Young drivers are more susceptible to alcohol impairment as compared to mature drivers (Peck et al., 2008) and females have less tendency to take risks in comparison with males of the same age group (Leung and Starmer, 2005).

Field investigations are generally carried out to analyze the driver behavior (Pathivada and Perumal, 2019) but, it is difficult to study the influence of psychoactive substances (like alcohol) on driving performance in real traffic. Driving simulators prove to be a better tool of research as they provide safe and controlled environment where the external effects on driving can be regulated (Meuleners and Fraser, 2015). Simulator-based approach is extensively used to study the changes in driver behavior (Brown et al., 2018; Hartman et al., 2015; Stein, 2012; Brown et al., 2013). The effect of alcohol on driving

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performance has been widely examined in the experimental studies with the help of driving simulators (Li et al., 2018; Christoforou et al., 2013; Du et al., 2016). Some of the recent driving simulator studies on alcohol-impaired driving performance are summarized in Table S1 in the supplement.

1.1. Research motivation

Since decades, researchers from western countries are studying the negative effects of alcohol on driver behavior (Irwin et al., 2017). In the last five to ten years, developing nations like China and Hong Kong have also started investigating the intoxication effects on their drivers (refer Table S1). Moreover, this area of research is relatively new for developing countries and scarcely explored. Inter-country differences exist between the developed and developing nations with respect to driver physiology, driving conditions, drinking habits, safety regulations and law enforcement (Khanal and Sarkar, 2014; Warner et al., 2011). For instance, western drivers have different BMI as compared to Asian drivers (Nishida, 2004) as BMI is known to influence the driving performance of drivers (Smarandescu et al., 2014). Further, in developed nations like the USA, lane-based discipline is strictly followed and structured environment for driving is present. On the other hand, in a developing country like India, there are issues with heterogeneity of traffic, lane discipline and law enforcement (Khanal and Sarkar, 2014; Maji et al., 2018). Also, research has shown that significant differences are observed in driving behaviors of developing and developed countries (Warner et al., 2011). Moreover, the definition of aggressive driving is linked to the cultural background of the country and varies across different cultures (Khanal and Sarkar, 2014).

With respect to drinking habits, it is known that heavy episodic drinking is more prevalent in western countries (World Health Organization, 2018). The level of alcohol consumption by an individual depends on the variants in enzymes involved in alcohol metabolism (Edenberg, 2007). The differences in alcohol metabolism of Asians and western population exist due to the variation in secretion rate of these enzymes. For instance, in Asians, an allele of Alcohol Dehydrogenase (ADH) enzyme is found in high frequency which protects them against alcoholism whereas in western population, this allele is not very common (Edenberg, 2007). This protective effect is stronger in Asian population as compared to western population (Edenberg, 2007).

All the above-mentioned differences influence the driving attitude which is a crucial factor affecting the driving behavior (González-Iglesias et al., 2015). While formulating the policies to counter the alcohol-impaired driving, the policy makers and traffic safety regulatory bodies shall consider the regional and cultural differences specific to the drivers of a particular country. Therefore, it is required to explore the effects of alcohol use on the physiological and behavioral changes in the drivers of a developing country like India which is largely understudied.

During the literature review, mixed findings were observed for various performance measures. Comparison of findings of different studies revealed that all the performance measures did not show significant impairment at different BAC levels (Table S1). This may be due to the diversity of sample considered in different studies or due to the variation in BAC levels/alcohol dose at which the experiments were conducted. Therefore, based on the literature, it may not be possible to select a specific performance indicator which can detect the impaired state of drivers at different BAC levels.

With respect to the above research gaps, the objectives of the present study are as follows:

- 1 To conduct a comparative assessment of the influence of different BAC levels on longitudinal and lateral driving performance measures.
- 2 To examine the effect of different BAC levels on self-perceived physiological changes in the drivers.

- 3 To identify the most suitable performance indicator which can detect the alcohol-impaired state of the driver.

The present study analyzed the effects of four BAC levels (0%, 0.03%, 0.05% and 0.08% BAC) on the physiology of Indian drivers and their driving performance in Indian driving conditions (heterogeneous traffic) with the help of a driving simulator experiment. The BAC levels were decided based on the maximum legal limits for driving in different countries.

2. Materials and methods

2.1. Participants

The study was conducted according to the guidelines of ethical approval obtained from the Institute Ethics Committee (IEC) of Indian Institute of Technology, Bombay (Reference No: IITB-IEC/2017/024). Participants were invited for the study and they were included only if they possessed a valid driving license and had normal or corrected-to-normal vision. The exclusion criteria were self-reported physical or mental illness, going through any medication, being pregnant or going through menstrual cycle (for females). Seventy-five participants (mean age = 24.5 years, SD = 3.56) were recruited for the study; this includes fifty-six males and nineteen females. They held Indian driving licenses for an average period of 4.6 years (SD = 3.33). The selected participants were informed about the experimental procedure and they signed an informed consent form before participating in the study.

2.2. Apparatus

In this study, simulation experiments were conducted on a static driving simulator with three 42 in. screens, fully instrumented, with 150° horizontal view (refer Fig. S1 in the supplement). The controls of driving simulator were similar to an actual car, including the power steering, clutch, brake and accelerator pedals, side and rear-view mirrors, gearbox, turn indicators and speedometer along with the audio cueing to simulate the engine sound while driving (Choudhary and Velaga, 2019a, 2019b). The driving environment was created with the help of SimVista and SimCreator software (Choudhary and Velaga, 2017a). Lion Alcolmeter SD-500, a breath analyzer manufactured by Lion Laboratories, UK, was used to measure the Blood Alcohol Concentration (BAC) of the participants (Leung et al., 2012; Freydier et al., 2014).

2.3. Scenario design

The simulated driving environment comprised of a four-lane undivided carriageway with two-way traffic resembling the common road scenario of rural highways in India (Yadav and Velaga, 2019b). Heterogeneous traffic conditions were designed with mixed traffic environment and no-lane based discipline where vehicles do not move in their individual lanes and try to occupy the space on the road wherever they can perceive safe travel. The driving stretch was four kilometers long in all the driving conditions and the width of each road lane was kept at 3.5 m. The participants were instructed to adhere to the posted speed limit of 110 kmph and a warning tone was generated to inform the participants if they crossed the speed limit.

2.4. Questionnaire preparation

Two questionnaires were designed for the study (please refer the supplements). Questionnaire-1 recorded the drivers' demographics, their drinking habits and their alertness based on the Karolinska Sleepiness Scale (KSS) before the simulator driving. Questionnaire-2 measured the subjective impairment based on the self-reported performance of the drivers with respect to the factors such as mental

alertness, visual ability, attention, judgement ability and sense of the surroundings while driving. Participants self-analyzed their driving performance after each round of simulator drive and rated the measures on a scale of 1–10 where ‘1’ referred to the “lowest score” and ‘10’ referred to the “highest score”. Self-reporting methods are considered to have a reasonable level of validity and reliability (Del Boca and Darkes, 2003).

2.5. Experimental design

The participants were asked to refrain from alcohol and get a good night sleep before the experiment. A familiarization session was conducted before the test sessions where the participants were demonstrated about the handling controls of the driving simulator. After the demonstration, the participants were given a practice drive to get themselves familiarized with driving on car simulator. After the familiarization session, they were asked to fill the Questionnaire-1. Their BAC level was checked to ensure the absence of alcohol before the experimental driving. The participants’ driving performance were tested for two states, one with no alcohol or sober state (0% BAC) and the other in the intoxicated state at three BAC levels (0.08%, 0.05% and 0.03%) on the descending limb of BAC curve. This is because the decision to drink and drive is increased on the descending limb of BAC curve as the perceived danger to drive after drinking is reduced when the BAC is likely to decline (Morris et al., 2014). After completing the drive in a sober state, they consumed alcohol of their preference corresponding to the 0.08% BAC. The subjects were allowed to consume the alcoholic beverage of their own choice because in practical situations, people generally consume alcohol of their own choice before driving. The rate of alcohol metabolism varies among individuals and therefore, the alcohol dose varied for each participant based on their body type, weight and sex. The BAC level of the participants was continuously checked at every 5-minute interval after they started consuming alcohol. Driving in the intoxicated states was considered when the participants were within the range of 0.005% BAC (or 5 mg/100 ml) of the target BAC (i.e. 0.03%, 0.05% and 0.08% BAC). They were not informed about their BAC results during the experiment to reduce the expectation effects while driving. The mean length of time taken by the participants from 0% to 0.08% BAC was 51 min (± 12.42 min), from 0.08% to 0.05% BAC was 29 min (± 11.28 min) and from 0.05% to 0.03% BAC was 28 min (± 9.32 min). At each BAC level, the participants drove on the designed road scenario and after each drive, they rated their physiological states in the Questionnaire-2. The starting points of the scenario were kept different for all the four driving states to minimize the learning effect and were randomized across the participants. An overview of the experimental design protocol is shown in Fig. 1.

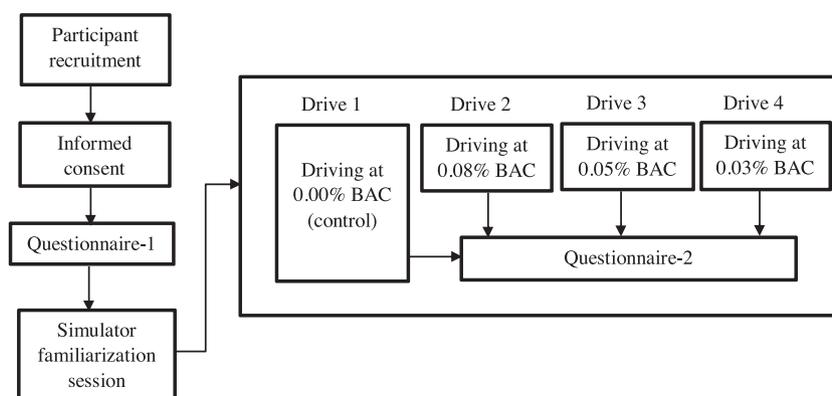


Fig. 1. An overview of experimental design.

2.6. Driving performance measures

Driving behavior of the participants under the sober and intoxicated states was analyzed with the help of driving performance measures obtained from the driving simulator and the self-reported physiological measures obtained from the questionnaire. The performance indicators obtained from the driving simulator included (1) longitudinal control measures (mean and standard deviation of longitudinal speed) and (2) lateral control measures (standard deviation of lane position, mean and standard deviation of steering wheel angle). The effect of different BAC levels on the performance indicators was analyzed with repeated-measures ANOVA tests using SPSS Version 22 software. Mauchly’s test of sphericity was conducted for the performance measures and if the sphericity was violated, Greenhouse-Geisser adjustment was done to adjust the degrees of freedom. The main effect of alcohol on all the performance indicators was checked at 5% significance level. Post-hoc tests were performed to identify and demonstrate the statistical differences among the different BAC level groups if the main effect of alcohol was observed on the performance measures.

3. Results

3.1. Descriptive statistics

The mean and standard deviation of age of male drivers were 24.8 years and 3.79 years, and of female drivers were 23.7 years and 2.67 years. About 60% of the subjects consumed alcohol rarely (at most once a week), 26.7% consumed sometimes (once or twice a week) and remaining 13.3% consumed often (more than twice a week). When asked about the preferred form of alcohol, beer was the most favorite among the subjects (32.6%) followed by whiskey (28.3%), Vodka (13.8%), Rum (12.3%), Wine (10.1%) and Gin (2.9%). The demographic and socio-economic characteristics of the participants are presented in Table 1.

3.2. Alertness level

The alertness of the participants before the experiment was measured with the help of Karolinska Sleepiness Scale (KSS) where the participants rated their alertness level on a scale of 1 to 9, ranging from “Extremely Alert” to “Extremely sleepy, fighting sleep” (Kaida et al., 2006; Mahajan et al., 2019). The mean KSS score of the participants was found to be 2.19 (SD = 0.84) on the KSS scale before the start of the experiment. It ensured that the participants were quite alert, and the effect of fatigue did not influence the experimental study.

Table 1
Demographic and socio-economic characteristics of selected participants.

Variable	Type	Category	Mean	SD	Percentage
Age (years)	Continuous		24.53	3.56	
Gender	Categorical	Male			74.7
		Female			25.3
Income (Indian rupee)	Categorical	Less than 2 lakhs per annum			41.3
		2-5 lakhs per annum			30.7
		5-10 lakhs per annum			14.7
		More than 10 lakhs per annum			13.3
Education	Categorical	Post graduate			44.0
		Graduate			52.0
		Intermediate			4.0
Occupation	Categorical	Government job			17.3
		Private job			24.0
		Other (student or unemployed)			58.7
Years of holding driving licence	Continuous		4.61	3.33	

3.3. Effects on driving performance measures

3.3.1. Mean speed

The main effect of BAC on mean speed of the participants was statistically significant ($F(2.56, 189.92) = 22.69$, $p < 0.001$; partial $\eta^2 = 0.23$). Fig. 2(a) showed that mean speed of the participants increased consistently with increase in the BAC levels. In the post hoc test (Table 2), the contrast analysis showed that the mean speeds in all the alcohol-impaired states (0.03%, 0.05% and 0.08% BAC) were significantly higher than the sober state (0% BAC). Moreover, mean speeds significantly increased for 0.08% BAC compared to 0.03% as well as 0.05% BAC, as observed in the pairwise contrast analysis.

3.3.2. Speed variability

Speed variability is defined as the standard deviation of vehicle speed for each driver (measured in kilometers per hour). Significant effect of alcohol was observed on the speed variability ($F(3, 222) = 2.774$, $p = 0.042$, partial $\eta^2 = 0.036$). Fig. 2(b) revealed that the standard deviation of longitudinal speed increased with increasing BAC levels. The pairwise comparison revealed that the standard deviation of longitudinal speed was significantly higher at 0.08% BAC compared to the sober state, but the increment was not significant for other intoxicated states i.e. 0.03% and 0.05% BAC (Table 2).

3.3.3. Lane position variability

Lane position variability is defined as the standard deviation of lateral offset of the vehicle position from center line measured in meters (Choudhary and Velaga, 2017b). The main effect of BAC on the lane position variability was found to be statistically significant ($F(2.44, 180.51) = 3.096$, $p = 0.038$, partial $\eta^2 = 0.04$) and its variation with increasing BAC levels is presented in Fig. 2(c). Post-hoc comparison analysis showed significant increase in lateral position standard deviation at 0.08% BAC compared to 0% BAC but for the other two BAC states, the increment was not significant. Additionally, lane position variability at 0.08% BAC was significantly higher compared to 0.03% BAC but not to 0.05% BAC.

3.3.4. Mean steering wheel angle

Steering wheel angle is defined as the angle subtended between the front of the vehicle and direction of the steered wheel (measured in degrees). The results indicated significant differences in the mean steering wheel angle at different BAC levels ($F(3, 222) = 8.337$,

$p < 0.001$, partial $\eta^2 = 0.101$). Mean steering wheel angles of the participants at different BAC levels are presented in Fig. 2(d). It was observed that the mean steering wheel angle increased with the increase in BAC level. According to post hoc tests shown in Table 2, drivers driving at 0.05% BAC and 0.08% BAC showed significantly higher steering wheel angle than at 0% BAC.

3.3.5. Steering wheel angle variability

Standard deviation of the steering wheel angles for each driver is termed as steering wheel angle variability (measured in degrees). Fig. 2(e) shows that the variation in steering wheel angle of the participants increased with increasing BAC levels but ANOVA analysis revealed that this increment was not significant between the sober drivers and intoxicated drivers ($F(2.574, 190.464) = 1.589$, $p = 0.199$, partial $\eta^2 = 0.021$).

3.3.6. Physiological impairment

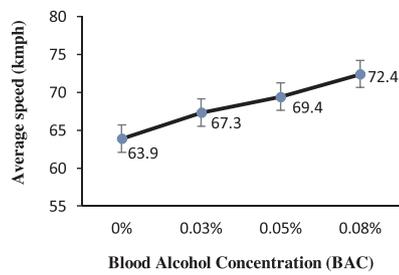
Based on the ANOVA tests, the main effect of alcohol was found to be significant on the mental alertness of the drivers ($F(2.522, 186.621) = 23.104$, $p < 0.001$, partial $\eta^2 = 0.238$), vision ($F(2.677, 198.126) = 21.598$, $p < 0.001$, partial $\eta^2 = 0.226$), judgement ability ($F(2.342, 173.301) = 19.735$, $p < 0.001$, partial $\eta^2 = 0.211$), attention on the road ($F(2.479, 183.426) = 21.911$, $p < 0.001$, partial $\eta^2 = 0.228$) and sense of the surroundings ($F(3, 222) = 9.872$, $p < 0.001$, partial $\eta^2 = 0.118$) while driving. The means and standard deviations of the subjective performance measures are summarized in Table 3. The results indicated that the impairment in drivers' mental alertness, visual ability, ability to judge, attention on the road while driving and sense of the surroundings increased with the increase in BAC levels. Post-hoc comparison analysis (Table 4) revealed the extent of impairment from one BAC level to another. For instance, all the three intoxicated states (0.03%, 0.05% and 0.08% BAC) showed significant impairment in the physiological measures with respect to 0% BAC except for 'sense of the surroundings' which did not show significant difference between 0.03% and 0% BAC (p -value = 0.18). Moreover, judgement ability, attention and sense of surroundings of participants showed significant differences between 0.03% and 0.08% BAC (Table 4). While comparing 0.05% and 0.08% BAC, it was observed that only 'judgement ability' and 'sense of surroundings' displayed significant variation.

4. Discussion

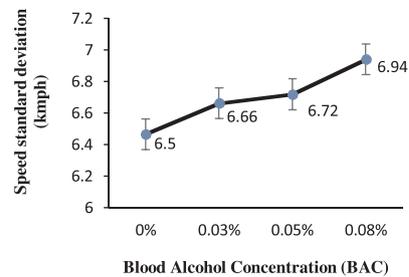
The acute effects of alcohol were investigated on the physiology of 75 drivers and their driving performance through a questionnaire and driving simulator experiments. The exploratory study comprised of experimental tests for evaluating alcohol-induced driving impairment at four BAC levels (0%, 0.03%, 0.05% and 0.08%).

Self-perceived impairment ratings of drivers under the sober and intoxicated conditions confirmed their physiological impairment during alcohol-impaired driving. Alcohol diminished their attention on the road ahead, judgement ability and mental alertness while driving. They faced difficulties in sensing the surroundings and their vision got impaired after consuming alcohol. With the increase in BAC levels, the self-perceived performance ratings deteriorated. These results strengthened the findings of the previous studies on the drivers of other countries (Zhao et al., 2014; Moskowitz and Fiorentino, 2000).

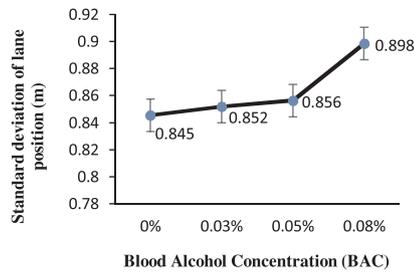
Driving performance of the drivers was measured with respect to their mean and standard deviation of speed, standard deviation of lane position, mean and standard deviation of steering wheel angle. Mean speed is a commonly used indicator of driving performance in simulator studies (Fillmore et al., 2008). Drivers usually tend to drive faster after drinking and show delayed response to any external stimuli (Christoforou et al., 2013). Further, lane position variability has been shown as a receptive indicator of alcohol intoxication (Laude and Fillmore, 2016). Higher lane position variability indicates poorer



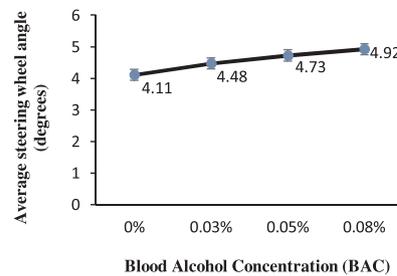
(a) Means of average speed at all BAC levels



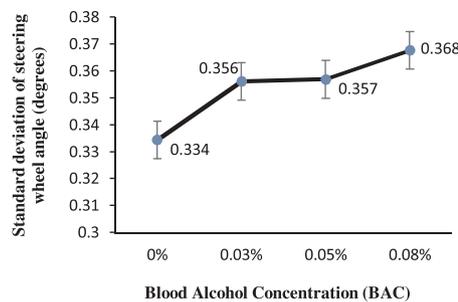
(b) Means of speed standard deviation at all BAC levels



(c) Means of lane position standard deviation at all BAC levels



(d) Means of average steering wheel angle at all BAC levels



(e) Means of steering wheel angle standard deviation at all BAC levels

Fig. 2. Means (SEs) of the driving performance measures at different BAC levels.

driving precision. It has been used by various researchers as the primary indicator of the detection of drivers' impairment (Zhao et al., 2014). Smooth steering movements are associated with sober drivers while drivers under the influence of alcohol are slow in steering adjustments, especially during turning movements (Li et al., 2018). With increasing BAC levels, the present study showed that alcohol intoxication resulted in significant increase in driving speeds, speed variability, lane position

variability, and mean steering wheel angle. Moreover, the results also confirmed that the driving performance was deteriorated even at low alcohol doses.

The present study conducted a comparative assessment of various driving performance measures and drivers' self-perceived physiological changes while driving under the influence of different BAC levels. The study identified the driving performance measures which are

Table 2 Results of contrast analysis of driving performance measures.

Driving state 'A'	Driving state 'B'	Mean speed		Speed variability		Lane position variability		Mean steering wheel angle	
		Mean difference (A-B)	p-value	Mean difference (A-B)	p-value	Mean difference (A-B)	p-value	Mean difference (A-B)	p-value
BAC 0.00% (sober)	BAC 0.03%	-3.432	0.018*	-0.196	0.826	-0.006	0.461	-0.364	0.269
	BAC 0.05%	-5.531	< 0.001*	-0.253	0.471	-0.011	0.319	-0.614	0.007*
	BAC 0.08%	-8.518	< 0.001*	-0.474	0.049*	-0.053	0.042*	-0.809	< 0.001*
BAC 0.03%	BAC 0.05%	-2.099	0.084	-0.057	0.969	-0.004	0.492	-0.250	0.530
	BAC 0.08%	-5.086	< 0.001*	-0.278	0.140	-0.046	0.035*	-0.446	0.118
BAC 0.05%	BAC 0.08%	-2.987	0.014*	-0.221	0.820	-0.042	0.054	-0.196	0.862

* p < .05.

Table 3
Self-reported physiological impairment of drivers at different BAC levels (on 1–10 scale).

	0% BAC	0.03% BAC	0.05% BAC	0.08% BAC	p-value
	Mean (SD)				
Mental alertness	8.92 (1.15)	7.75 (1.58)	7.60 (1.63)	7.52 (1.91)	< 0.001
Visual ability	9.25 (0.93)	8.17 (1.82)	7.89 (1.71)	7.87 (1.78)	< 0.001
Ability to judge	8.68 (1.22)	7.85 (1.50)	7.75 (1.78)	7.33 (1.84)	< 0.001
Attention on the road	8.85 (1.24)	8.06 (1.39)	7.67 (1.75)	7.55 (1.79)	< 0.001
Sense of the surroundings	8.41 (1.44)	7.92 (1.54)	7.81 (1.81)	7.27 (2.08)	< 0.001

significantly impaired at different BAC levels with respect to sober state (0% BAC). For instance, significant effects of 0.08% BAC were observed on mean speed, speed variability, lane position variability, and mean steering wheel angle. Significant effects of 0.05% BAC were prominent in mean speed and mean steering wheel angle whereas driving at 0.03% BAC significantly affected only the mean speed of the drivers. Various transportation applications such as forward collision warning systems and evasive steering assistance systems are mainly dependent on the vehicle speed and steering angle. Therefore, the combination of driving speed and steering angle can be helpful in detecting the impaired state of the driver under the influence of 0.05% BAC and above which comes under the legal BAC limit for driving in various countries like USA, UK, South Africa, Germany, etc.

Moreover, significant impairment was observed in drivers' attentiveness on the road, visual ability, mental alertness and judgement ability while driving at various BAC levels (0.03%, 0.05% and 0.08%). This shows that drivers can judge the extent of deterioration in their psychomotor control and can make a decision whether to drive or not under the influence of alcohol. The results support the findings of a study conducted in China (Zhao et al., 2014), where 84% of the drivers agreed that alcohol divided their attention while driving and impaired their judgement ability, and 72% agreed that their sense of direction declined after consuming alcohol. Drivers admitted that alcohol affected their driving control which is a fundamental reason to impair their driving skills (Yadav and Velaga, 2019b). This increases the crash probabilities during alcohol-impaired driving.

4.1. Research contribution

This study is the first attempt to examine the driving performance of Indian drivers under the influence of different alcohol levels (0.03%, 0.05% and 0.08%) in heterogeneous traffic conditions through a driving simulator experiment. The results confirmed significant increment in driving speed at 0.03% BAC which is the maximum BAC limit for driving in India according to the Motor Vehicle Act (1988). In India, over-speeding leads to around 70% of the traffic crashes (Ministry of Road Transport and Highways, 2017) and since alcohol-impaired drivers tend to drive faster than their usual speeds, it becomes more critical to crash risks. The present study may be helpful to the regulatory bodies in spreading awareness about the negative effects of alcohol on driver behavior.

Table 4
Results of contrast analysis of self-perceived physiological measures.

Driving state 'A'	Driving state 'B'	Mental alertness		Visual ability		Ability to judge		Attention on the road		Sense of the surroundings	
		Mean difference (A-B)	p-value	Mean difference (A-B)	p-value						
BAC 0.00% (sober)	BAC 0.03%	1.17	< 0.01*	1.08	< 0.01*	0.83	< 0.01*	0.79	< 0.01*	0.49	0.18
	BAC 0.05%	1.32	< 0.01*	1.36	< 0.01*	0.93	< 0.01*	1.18	< 0.01*	0.60	0.05*
	BAC 0.08%	1.40	< 0.01*	1.39	< 0.01*	1.35	< 0.01*	1.30	< 0.01*	1.14	< 0.01*
BAC 0.03%	BAC 0.05%	0.15	1.00	0.28	1.00	0.10	1.00	0.39	0.10	0.11	1.00
	BAC 0.08%	0.23	1.00	0.30	0.46	0.52	0.01*	0.52	< 0.01*	0.65	0.01*
BAC 0.05%	BAC 0.08%	0.08	1.00	0.02	1.00	0.42	0.03*	0.12	1.00	0.54	0.04*

* p < .05.

4.2. Limitations

There were a few limitations faced in the study. Alcohol-impaired driving experiments were conducted only for the descending limb of BAC curve. Future studies may investigate the effects of alcohol on both the ascending and descending limb of the BAC curve simultaneously. In this study, the driving simulator methodology was adopted instead of naturalistic field driving for analysing the alcohol effects on driver. This is because, in India, it is illegal to drive at the BAC level of 0.03% and above. Additionally, there was no control on the form of alcohol consumed which may have influenced the alcohol metabolism of the drivers. During the course of study, though adequate practice driving sessions were provided, repeated simulator drives may have inculcated progressive learning effect among the participants.

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Nothing declared.

Contributors

Ankit Kumar Yadav and Nagendra R Velaga designed the course of study and experimental setup. Ankit Kumar Yadav conducted the detailed literature review and carried out the driving simulator experiments in the laboratory under the supervision of Nagendra R Velaga. Ankit Kumar Yadav conducted the statistical analysis and wrote the first draft of the manuscript. Both the authors contributed to and approved the final manuscript submitted for publication.

Declaration of Competing Interest

No conflict of interest declared.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.drugalcdep.2019.107630>.

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