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Exploring driver behaviors during tailgating situations: a driving simulator study

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Abstract

The characteristics of drivers vary from one individual to another and one culture to another, leading to distinct driving behaviors exhibited by different drivers. This study aims to explore drivers' car-following behaviors during tailgating situations using the data collected through a driving simulator experiment conducted at Qatar University. Preliminary outcomes of this study explained that the reaction times do not significantly vary between males and females (of 20 to 30 years old) even though females showed shorter reaction times than males. Furthermore, compared to male drivers, female drivers tend to maintain a shorter spacing while tailgating. Both genders tend to maintain a longer spacing when following a sedan than when they follow a truck. Analysis of Time-To-Collision (TTC) values indicated that collision risk might be higher when a female driver tailgates a truck. Compared to their male counterparts, female drivers displayed more unsafe tailgating behaviors during tailgating situations, as indicated by a higher percentage of critical TTC values. The findings of this study could be useful in devising its-based safety interventions and calibrating car-following models considering the heterogeneity of driving behaviors and driver characteristics.

Keywords: Driver behavior; tailgating; car-following; traffic safety; driving simulator.

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1. Introduction

Characteristics of drivers differ from one to another. As a result, different drivers tend to display different driving behaviors [1]. On the other hand, there is a cultural dimension to driving behaviors [2-5]. For example, as empirically verified by Wang et al. [4], Chinese young males tend to maintain a higher speed and longer reaction times when avoiding risks on the road as compared to German young males. In addition, driver reactions could largely depend on the driving situation, e.g., under different weather conditions and different risky driving conditions [4, 6]. Given such aspects, predicting driver behaviors and generalizing them across different cultures or populations is difficult. Qatar is a unique country in terms of its diverse driving population, which includes drivers from a variety of subcultures [7-8]. Risky and aggressive driving behaviors among drivers in Qatar, who are from different cultures, have been reported in several previous studies and the acceptance of such behaviors by other drivers has also been studied [8]. As such, investigating driver behavior is critical, particularly from safety and operational perspectives.

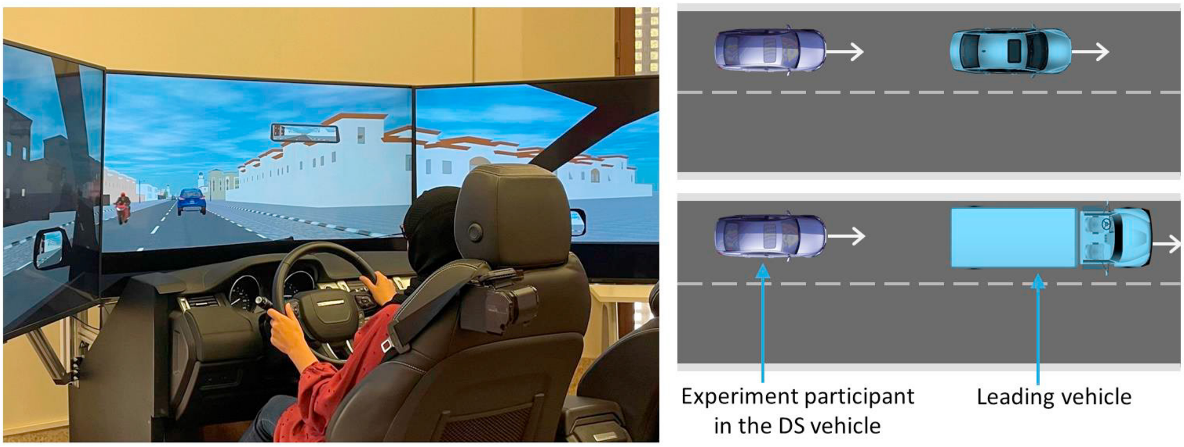
Using naturalistic trajectory data, several previous studies revealed that drivers' following behaviors vary depending on the front vehicle type [9-11]. However, within-subject design (the same subject is tested for different driving scenarios) was not possible and driver characteristics were not available as those studies used real-world data. In addition, given ethical issues, it is hard to reproduce critical situations in a real-world experiment. Driving Simulators (DS) can overcome such issues and be used to evaluate critical situations in simulated environments. Several previous studies have used the data collected through DS experiments to explore driver behaviors and reactions during critical situations. Wang et al. [4] investigated the risk aversion behaviors of Chinese and German young male student drivers in critical situations such as when a motorcycle changes the lane when a pedestrian crosses a road, and an animal crosses a road. The results of this study observed significant differences in terms of reaction times between the two groups. Xue et al. [12] explored drivers' brake reaction times (BRT) while answering the phone during three use modes (baseline, hands-free, and handheld) to answer two types of arithmetic problems (simple and complex). They concluded that the effect of cognitive load on drivers' BRTs decreased as situation criticality increased. A DS experiment was conducted by Broughton et al. [13] to investigate car-following behaviors under three visibility conditions and two speed levels. The findings of this study revealed that space headways, time headways, and speed standard deviations differed significantly across speed levels and visibility conditions. The influence of demographic variables (e.g., age and gender) and the desired speed on car following behaviors of Iranian drivers were explored by Ramezani-Khansari et al. [14] using the data from a DS experiment. The outcomes of this study explained that gender could significantly affect the car following behavior while age was not an influential factor. The influence of sleep deprivation on car-following behaviors was studied by Mahajan and Velaga [15] using a DS-based study conducted in India. They discovered that sleeping for 4.5 hours less per night for one or two days reduced critical time headway by 0.65 and 1.08 times, respectively, when compared to the baseline. According to these previous studies, various aspects, such as demography and the criticality of the situation, have been studied during car-following situations. However, given the cultural dimension of driver behavior, the outcomes of such studies are not directly transferable to represent local conditions in other countries or regions. Furthermore, detailed analyses that focus on the parameters of car-following models have not been presented in these studies.

The current study aims to empirically explore driver behaviors during different critical tailgating situations, e.g., when the front driver is braking harshly to represent near-crash situations. Rear-end collisions have been identified as the most frequent type of crash [16-18]. Tailgating behavior is directly associated with the occurrence of rear-end collisions [17, 19]. The data were collected from a driving simulator (DS) study for different leading vehicle types and under different braking situations.

2. Driving Simulator Experiment

Driving simulators (DS) can be considered an effective tool to study driving behavior [20-21]. This tool creates a virtual driving environment that can be influenced by various driving situations, allowing experiments to be conducted under controlled conditions. The DS installed at the Qatar Transportation and Traffic Safety Center (QTTSC) at the College of Engineering, Qatar University will be used to conduct the experiments (Fig. 1 (a)). This

DS tool has been validated for speed perception and subjective validity, i.e., the resemblance of drivers' experience in the simulator to real-world [21]. A cockpit of a Range Rover Evoque model is used in this DS. Further, a force-feedback steering wheel with indicator, dashboard speedometer, automatic transmission gearbox, and genuine pedals are included in the setup. SCANeR studio software (www.avsimulation.com/scaner-studio/) is used for high-speed graphics and sound. Three horizontally connected screens with a field of view of 135 degrees are used to display graphics with a resolution of 5760 x 1080 pixels with a refresh rate of 60 Hz. This DS can record a wide range of data, including lateral/longitudinal position, lateral/longitudinal speed, lateral/longitudinal acceleration, the number of speeding tickets, reaction time, and so on.



(a) (b)

Fig. 1. (a) The driving Simulator installed at Qatar University; (b) considered experiment scenarios.

For this particular experiment, two leading vehicle types were considered, i.e., a sedan and a heavy vehicle, as schematically shown in Fig. 1 (b). Continuous speed profiles for the leading vehicles were determined and set considering three deceleration levels to represent mild braking (approximately 2.21 m/s2), moderate braking (approximately 4.39 m/s2), and harsh or emergency braking (approximately 6.31 m/s2) situations. These values were set in accordance with the deceleration values reported in previous studies as summarized in Samson et al. [23]. Two speed limits, i.e., 50 km/h and 80 km/h, were considered and only the outcomes for the 50 km/h case (that represents residential roads in Qatar) are presented in this paper. The internal review board of Qatar University granted ethical approval for the study (QU-IRB 1819-EA/23). Experiment participants were recruited through official emails and personal contacts. 61 people, out of which 18 were females, signed the consent and completed the experiment. Their ages ranged from 19 to 50 approximately.

3. Results

3.1. Reaction times

According to car-following modelling concept, the actions of the driver in the following vehicle, such as maintaining a safe distance through acceleration or deceleration, are determined by the actions of the leading vehicle. The stimulus-response approach, commonly used to model car-following behaviour, explains that the following car responds (e.g., by accelerating or decelerating) to a stimulus (a change in spacing or relative speed) after a specific time delay known as the reaction time. Chandler et al. [22], one of the earliest car-following models, established a linear relationship between the acceleration of the following vehicle (response) and the response (relative speed) as follows;

$$a_F(t+\tau) = \lambda[V_L(t) - V_F(t)] \quad (1)$$

where, a_F is the acceleration of the following vehicle, $V_L(t)$ is the current speed of the leading vehicle, $V_F(t)$ is the speeds of the following vehicle, τ is the reaction delay and λ is the sensitivity factor. Based on this concept, Gurusinghe et al. [24] described a graphical method that can be used to estimate time varied reaction times. In this study, we used the same approach to estimate the reaction times of the following drivers as shown in Fig. 2. It can be observed that when the front vehicle brakes sharply, the reaction times are remarkably shorter. In contrast, for the situation when the front vehicle accelerates, the reaction times are comparably longer. This observation indicates that the drivers are more sensitive to sudden speed reductions of the front vehicle. Further studies are required to comprehensively explore such phenomena.

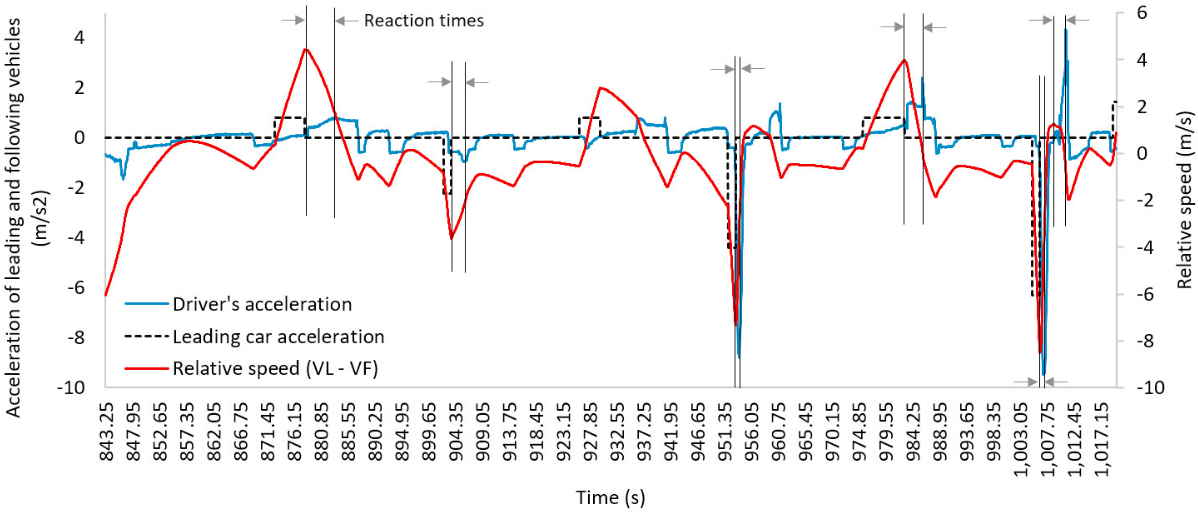


Fig. 2. Estimating reaction times using acceleration and relative speed plots.

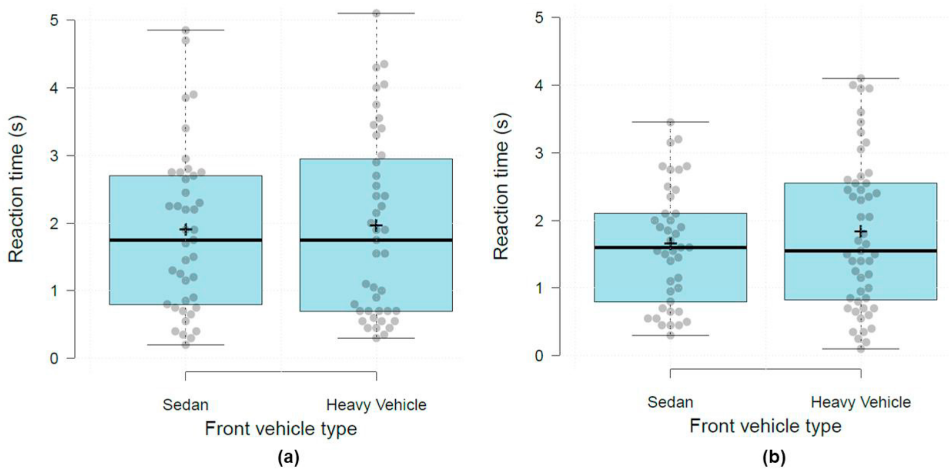


Fig. 3. Boxplots of reaction times for (a) male drivers and; (b) female drivers. The symbol "+" indicates the sample mean.

Initially, the data from 10 male subjects and 10 female subjects, whose ages ranged approximately from 20 to 30 years, were used to estimate time-varied reaction times. This was done mainly to eliminate the effect of age. Boxplots of the reaction times are shown in Fig. 3. Average (± standard deviation) of reaction times for male drivers when following a sedan and a heavy vehicle (truck) were estimated as 1.86 s (± 1.21 s) and 1.93 s (± 1.36 s), respectively. For female drivers, these values were 1.62 s (± 0.88 s) and 1.79 s (± 1.14 s), respectively. It can be noted that male drivers have longer reaction times as compared to female drivers. However, the statistical tests confirmed that the difference between median reaction times was statistically not significant (Kruskal-Wallis test, H statistic = 0.5765, p-value = .90179). These reaction times are slightly larger than the reaction times reported by Ranjitkar et al. [25] which were estimated using the data collected from a field experiment. It should be noted that in this study, the reaction times for all acceleration and deceleration situations (throughout the experiment) were considered together.

3.2. Spacing

When the speed of the following vehicle is larger than the leading vehicle the following vehicle closes to the leading vehicle. Then, to avoid a potential collision and to maintain a safer spacing, the following driver reduces the speed. This leads to an increase in spacing again. This phenomenon is explained in Fig. 4. From Fig. 4, it can be noted that the variation spacing is higher for male drivers as compared to female drivers. Average (± standard deviation) spacing for male drivers when following a sedan and a heavy vehicle (truck) were estimated as 26.96 m (± 15.93 m) and 25.11 m (± 9.86 m), respectively. For female drivers, these values were 23.61 (± 9.67 m) and 22.75 m (± 8.74 m), respectively. It can be noted that on average, female drivers tend to keep shorter spacing during tailgating situations as compared to female drivers. Both genders tend to maintain a longer spacing between vehicles when following a sedan compared to when they follow a truck. Statistical tests confirmed that the differences between these mean values were statistically significant. (t-stat, p-value) for the differences of means for males following a sedan and heavy vehicle, and females following a sedan and heavy vehicle were (6.409, < 0.001) and (9.129, < 0.001), respectively.

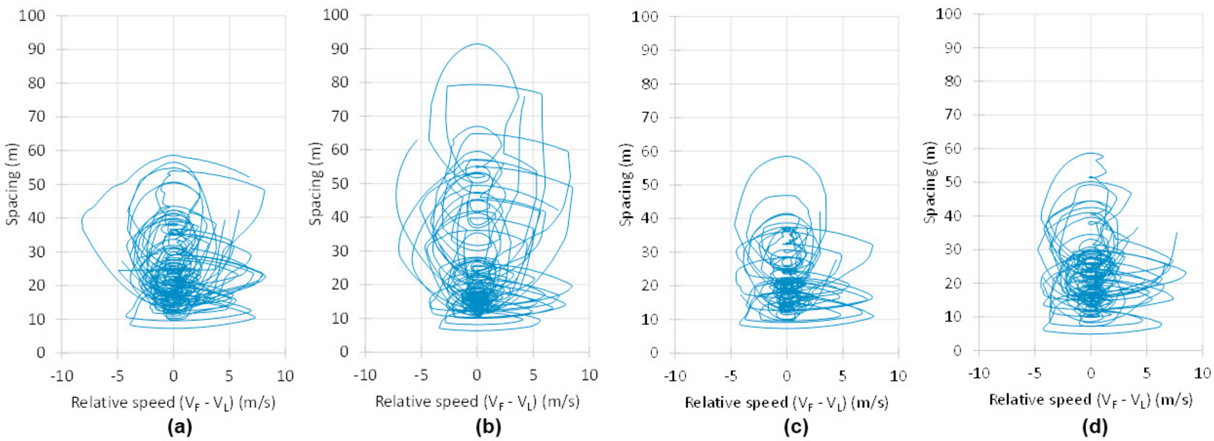


Fig. 4. Relative speed ($V_F – V_L$) versus spacing diagrams for (a) male drivers following a truck; (b) male drivers following a sedan; (c) female drivers following a truck; (b) female drivers following a sedan.

3.3. Time-to-collision (TTC)

TTC refers to the duration it takes for two vehicles to collide if they maintain their current speed and trajectory. As per the TTC concept, this value is calculated for each time step as a time series along a specific road segment. For rear-end collisions that are common in tailgating situations, TTC was calculated as follows;

$$TTC(t) = \frac{X_L(t) - X_F(t) - l_L}{V_F(t) - V_L(t)} \; ; \; \forall \, V_F(t) > V_L(t) \tag{2}$$

where, $X_L(t)$ and $X_F(t)$ denotes the positions of leading and following vehicles, respectively. l_L denotes the length of the leading vehicle.

An example of the TTC time series is shown in Fig. 5 along with the speed profiles of leading and following vehicles. It can be understood from Fig. 5 that TTC is continuously changing as the speeds of vehicles and spacing between vehicles are changing. Local minimum points of the TTC time series, characterize the most critical situations. It can be understood that the most unsafe instant, i.e. the lowest TTCs, occurs when the leading vehicle suddenly brakes (at moderate or harsh deceleration rates).

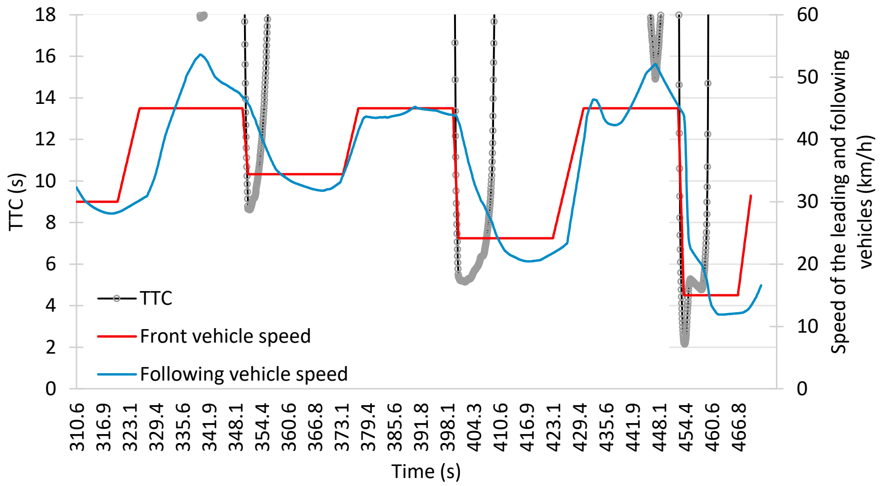


Fig. 5. Change of TTC with front and rear vehicle speeds.

Minimum TTC values were extracted for the above-mentioned 20 samples (10 males and 10 females). The average (± standard deviation)of minimum TTC values for male drivers when following a truck and a sedan were estimated as 1.86 s (± 0.74 s) and 2.23 s (± 1.48 s), respectively. For female drivers, these values were 1.45 s (± 0.80 s) and 1.74 s (± 0.85 s), respectively. From these statistics, it can be suggested that the most dangerous situations may expect when a young female driver follows a heavy vehicle. However, the statistical tests confirmed that the difference between TTC values was statistically not significant (Kruskal-Wallis test, H statistic = 1.9104, p-value = .9122). Overall, minimum TTC values were less than 1.5 s for 50% and 64% of male and female drivers, respectively. This threshold TTC value, i.e., 1.5 s, has previously been used as the critical value for analyzing conflicts [26].

4. Conclusions

This article presented preliminary findings from an empirical study based on a data-driven approach, aiming to investigate drivers' car-following behaviors in tailgating situations on residential roads with a speed limit of 50 km/h. The trends explained that, the average reaction time of males is larger than that of females when tailgating (even though the means were statistically insignificant). Furthermore, the mean reaction times of drivers when following a truck were larger than the mean reaction time when following a sedan. In comparison to normal acceleration and deceleration situations, the following drivers' reaction times were remarkably shorter when the front vehicle braked at moderate and harsh deceleration rates (or in an emergency). This observation suggests that close-range tailgating poses an immense safety hazard. Through the provision of early warning systems, e.g., through its-based in-vehicle technologies, such unsafe situations could be minimized.

Female drivers exhibited more unsafe behaviors during tailgating situations than their male counterparts, as indicated by a higher percentage of critical TTC values for female drivers compared with male drivers. Furthermore, it was also found that, on average, male drivers tend to keep longer spacing between their vehicle and the front vehicle than female drivers. This finding also suggests that young males are more likely to display safe behaviors than young females. Safety education and awareness campaigns should target young drivers (20-30 years old) to enhance road safety.

It should be noted that the outcomes of this study are based on the data extracted from the samples of 10 male and 10 female young (20 to 30 years old) drivers. Therefore, we do not intend to generalize the findings at this stage. An analysis with a large sample size will be entailed to more comprehensively examine the tailgating behaviors considering other influencing factors, e.g., age, driving experience, socio-economic status, other front vehicle types, etc., in the future. In addition, the data collected in this study can be used to calibrate microscopic models considering the heterogeneity of driver characteristics and behaviors. It is possible to explore the operational and safety aspects of roads using such simulation tools calibrated for local conditions.

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