Research Article

Comparing the Effect of Age, Gender, and Desired Speed on Car-Following Behavior by Using Driving Simulator

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In this study, the effect of age, gender, and desired speed (DS) factors on General Motors car-following (CF) behavior was investigated. DS was defined as the speed selected by the driver in free driving situation. A low-level driving simulator was used to collect data. The CF model for each driver was calibrated by genetic algorithm. Gender and DS were effective in CF behavior, while the age factor was not. The drivers' sensitivity to the variables of speed and distance in the CF model increased with increasing the DS. The gender factor affected only the magnitude of deceleration which was higher in women. For further investigation, the effect of the desired speed on the time headway in the steady-state CF was also examined. DS factor was effective in steady-state CF behavior. As the DS increased, the time headway decreased. Examining CF threshold demonstrated that women maintained larger distance than men. Finally, it can be said that DS and gender would be more important than age to be considered in CF models.

1. Introduction

Driving behavior can be influenced by the individual characteristics of the drivers and it has been studied in various aspects. Minh and Sano modeled acceleration and deceleration of motorcycles at signalized intersections. They applied a dummy variable for motorcyclist's gender which was finally appeared significant [1]. Analyzing the effects of drivers' characteristics such as age, gender, and driving style on fuel efficiency demonstrated that there was significant difference in the driving fuel efficiency, on the highway, depending on the age and gender. The results indicated that the fuel efficiency of late middle age drivers was higher than the younger ones and that of female drivers was higher than male drivers [2].

Car-following (CF) is one of the main driving behaviors in the traffic flow that describes longitudinal trajectory of a vehicle in a lane and its interaction with leading vehicle(s) to keep safe distance through throttle and braking [3, 4].

Studying the effect of individual characteristics on CF is important from macroscopic and microscopic view.

There are a lot of studies about the relationship between drivers' characteristics and road accidents [5–9]. Improper or unsafe CF behavior is one of the reasons of rear-end collision [10, 11]. Thus, investigating CF can help to prevent and predict rear-end collision and also can enhance traffic safety. Several researches have confirmed that both the CF model and its estimated parameters can vary for different drivers and situations [12–17].

Ranny was one of the firsts to address the effect of individual characteristics on CF behavior. In addition to personal characteristics, including age, gender, marital status, and risk-taking, he also considered situational factors including time of day, weather, and type of roads to be effective [18]. Montgomery et al. found that gender and age (selecting 30 as the threshold) can affect time to collision at braking in following situation [19]. James and Hammit applied the trajectory data from the SHRP2 Naturalistic

Driving Study to calibrate three CF models including Gipps, Intelligent Driver Model, and Wiedemann 99. They clustered estimated parameters of models based on different drivers' characteristics. Driver age, income, and marital status were found as important criteria for clustering while gender, work status, and living status were not [20].

Chiabaut et al. developed an effective estimation method to examine and calibrate interdriver heterogeneity in Newell's car-following model. They found that different drivers may have different reactions to the same stimulus [21]. Kim and Mahmasani calibrated several CF models by using Next Generation Simulation project (NGSIM) data and examined the estimated parameters for the models. Their results showed a statistically significant difference between the sets of correlated and uncorrelated estimated parameters [22]. van Hinsbergen calibrated Helly and General Motors CF models by applying Bayesian method. They found that driver behavior could be fitted by different models and that there was heterogeneity in driver behavior [23]. Ranjekar et al. recorded the trajectory of 9 vehicles on a test road using Global Positioning System (GPS) and tested different CF models. They found that the error variations obtained from different individuals were greater than the error resulting from the use of different models, which can be due to the drivers' heterogeneity [24]. Chen et al. used NGSIM data to calibrate the MITSIM and the Intelligent Driver Models. They observed that the estimated parameters formed a hyperplane, in which no specific classification was distinguished and the data were scattered, which could be interpreted as heterogeneity in drivers [25].

In many of previous studies, it has only demonstrated that different CF models and estimated parameters are appropriate for different drivers and thus there is heterogeneity in drivers which must be considered. But the effect of the each drivers' characteristics on heterogeneity was not investigated because of the lack of information about drivers, as the trajectory data had been extracted from recorded videos [26]. In this study, the effect of drivers' characteristics on CF behavior was investigated by using driving simulator data. Second section is dedicated to methodology. Data collection is introduced in the third section. Results and discussion are explained in the fourth section. Finally, section five concludes the research.

2. Methodology

A model is needed to investigate the effect of drivers' characteristics on CF behavior, thus General Motors CF model has been used, which is given by

$$a_n(t) = c v_n^m \frac{\Delta v(t - \tau)}{\Delta x(t - \tau)}, \quad (1)$$

where $a_n(t)$ is the acceleration of subject vehicle at time t , $v_n(t)$ is the speed of the subject vehicle at time t , t is the reaction time ($\tau = 0.7$ sec [12]), $\Delta v(t - \tau)$ is the relative speed at time t minus τ , $\Delta x(t - \tau)$ is the space headway at time t minus τ , n is the vehicle index of the follower vehicle, and c, l, m are the parameters of the model.

Maximum following distance has been considered 90 m. In other words, 90 m has been postulated as the threshold for starting car-following behavior and the trajectory data at longer distance have not been used and considered as free driving situation [27]. This model is one of the most well-known CF models that is still used to study driving behavior. Although this model has disadvantages such as insensitivity to distance when two cars are at the same speed, simplicity and comprehensibility have led to it still being used in many studies.

The parameters for the acceleration and deceleration situations must be calculated separately [28, 29], and the focus of this paper is on the deceleration CF model. To compare the effect of drivers' characteristics on CF behavior, the model has been calibrated for the data of each participant by using a genetic algorithm. By doing so, three parameters of c , m , and l have been obtained for each driver. These parameters can indicate the effects of magnitude of deceleration (sensitivity), speed, and distance in the CF model, respectively. Regarding the concept and effect of each variable, ranges have been considered for parameters: c between 0 and 3, m between 0 and 1, and l between 1 and 2.

From the personal characteristics, three factors of gender, age, and desired speed (DS) have been considered as drivers' characteristics. Age and gender have been evaluated in many previous studies. The DS was also added here to be examined as new factor. The DS has been defined the (average) speed selected by the driver in free driving mode. The DS may be an indicator for measuring the driver's aggression. Therefore, the difference in choosing the DS may spread to other driving behavior such as CF. To obtain the DS, all speeds recorded in free driving condition were gathered and then averaged out. Estimated parameters were categorized based on age, gender, and DS and were analyzed using statistical tests.

Given that gender was expected to be an important factor, at first, the data were separated by gender and then men group's data were categorized based on the age (over and under 35 years old) and DS (over and under 95 km/h) because there was more diversity in the men group. At the end, men and women's data were compared. One of the objectives of this research was to investigate the DS as an affecting factor on the CF behavior; therefore, for further investigation, the effect of the DS on the distance in steady-state CF has been discussed. In the steady-state CF, two consecutive vehicles in the same lane or path have almost the same and constant speed. Here, when the speed difference was less than 5 km/h, the speeds were considered equal [30, 31].

All data were extracted from leading and following vehicle trajectories in 0.1 sec intervals. The use of driving simulator and its data for research purposes can raise the question of whether driving simulator data are sufficiently valid. The answer to this question itself requires research and experimentation in which real data are compared with simulator data and have been the subject of much research. There are studies that only validate driving simulator data for specific factors such as speed and distance [32–34]. Ramezani-Khansari et al. investigated the validation of driving simulator for CF behavior [35].

3. Data Collection

28 women and 126 men participated in the driving test. 4 men's data were dropped because of simulator sickness. The age ranges of female and male drivers were between 19 and 28 and between 18 and 58, respectively. Figures 1 and 2 show the age distribution of drivers for each gender. The characteristics of participants are mentioned in Table 1.

The test time of each participant was divided into two parts, which are

Warm Up. In this step, the driver drove completely freely to adapt to the driving simulator. Warm up was considered about 5 to 10 minutes. This time could vary according to the age and ability of the participants and ended with their signal [36]. At the end of the warm up, she/he was asked to stop the car and rest for a few minutes in order to get ready for driving test.

Driving Test: In main driving, participants drove about 10 to 15 minutes on a highway.

4. Results and Discussion

First, the effect of age and DS factors in the men group was investigated. Then, the CF behavior between men and women was compared. Finally, different GM CF models were presented considering the effect of factors. Furthermore, time headway in steady-state CF was investigated based on the DS.

4.1. Age and Desired Speed Factors. To evaluate the effect of age on CF behavior, men were divided into over and under 35 years, young, and midage subgroups, respectively. The results of two-sample *t*-test (Table 2) showed that *P* value was greater than 0.05 for all parameters and the statistical test could not reject the null hypothesis (equality of means). Therefore, it can be inferred there is no significant difference between the estimated parameters of young and midage groups in male drivers. In other words, age would have no effect on CF behavior and it cannot be a factor for classifying drivers. So, DS was studied as an affecting factor. Participants' DSs were between 75 and 115 km/h.

Male drivers were divided into two categories of over and under 95 km/h (median of DS data) based on the DS. Table 3 examines the difference between the parameters of CF model between the two DS groups of men.

The results of two-sample *t*-test of three parameters showed that the difference between men's DS groups would be significant. In other words, it can be said that the classification based on the DS can express the differences in CF behavior.

Given that the statistical test showed there would be a significant difference in the classification based on the DS, the question arises whether drivers in a certain age group tend to a certain DS. The age distributions of drivers for the DS groups, upper and lower 95 km/h, are depicted in Figures 3 and 4. They intuitively show no difference.

The statistical test in Table 4 shows that there would be no significant difference between the two men's DS groups. So,

FIGURE 1: Age distribution of male drivers participating in driving simulator.

FIGURE 2: Age distribution of female drivers participating in driving simulator.

TABLE 1: The characteristics of participants.

	Age*	Gender	Desired speed
Mean	30.32	0.87	88.37
Standard error	1.38	0.04	1.22
Median	26.00	1.00	89.00
Mode	21.00	1.00	97.00
Standard deviation	10.89	0.34	9.58
Min.	18.00	0.00	70.00
Max.	58.00	1.00	121.00

* Age: man = 1 and woman = 0.

the DS would be a factor independent of the age, and the DS would not increase or decrease by increasing the age of driver.

4.2. Gender Factor. After examining the age and DS factors, the gender factor has been discussed. The maximum DS in the women's group was 95 km/h. Hence,

TABLE 2: Two-sample t -test of CF parameters between the men groups categorized based on age.

	c		m		l	
	Age < 35	Age > 35	Age < 35	Age > 35	Age < 35	Age > 35
Mean	0.5269	0.4602	0.2277	0.2580	1.1360	1.164
Variance	0.1106	0.1150	0.0683	0.0926	0.0437	0.045
$P(T \leq t)$ one-tail	0.3574		0.2612		0.2221	
t critical one-tail	1.6549		1.6547		1.6551	
$P(T \leq t)$ two-tail	0.7148		0.5224		0.4442	
t critical two-tail	1.9756		1.9753		1.9761	

TABLE 3: Two-sample t -test of CF parameters of the model between the men groups categorized based on DS.

	c		m		l	
	DS < 95 km/h	DS > 95 km/h	DS < 95 km/h	DS > 95 km/h	DS < 95 km/h	DS > 95 km/h
Mean	0.3357	0.8487	0.2697	0.1758	1.1081	1.2022
Variance	0.0216	0.2618	0.0870	0.0495	0.0334	0.0568
$P(T \leq t)$ one-tail	0.0012		0.0209		0.0033	
t critical one-tail	1.6547		1.6547		1.6547	
$P(T \leq t)$ two-tail	0.0026		0.0419		0.0066	
t critical two-tail	1.9753		1.9753		1.9753

FIGURE 3: Age distribution of male drivers with DS under 95 km/h.

the women group was compared to men group with DS lower than 95 km/h (Table 5), because it was demonstrated in the previous section that the DS can be an important factor.

The two parameters m and l did not show a significant difference, while the parameter c was significantly higher in the group of women (roughly 2 times larger). The m , l , and parameters indicate the driver's sensitivity to the speed, distance, and magnitude of deceleration between the two vehicles, respectively. In other words, the gender factor only affected the magnitude of deceleration.

FIGURE 4: Age distribution of male drivers with DS over 95 km/h.

TABLE 4: Two-sample t -test of driver age between men's DS groups.

	DS < 95	DS > 95
Mean	30.9	28.5
Variance	121.62	93.10
$P(T \leq t)$ one-tail	0.1457	
t critical one-tail	1.6526	
$P(T \leq t)$ two-tail	0.2914	
t critical two-tail	1.9721	

4.3. Desired Speed and Time Headway. To investigate whether the DS is effective in other aspects of CF behavior, the relationship between time headway (TH) in steady-state CF and DS was studied. Moreover, it was compared with the

TABLE 5: Two-sample t -test of CF parameters between men and women groups.

Parameters	c		m		l	
Gender group	Men	Women	Men	Women	Men	Women
Mean	0.3357	0.7524	0.2697	0.2855	1.1081	1.0844
Variance	0.2313	0.2116	0.0870	0.1433	0.0334	0.0367
$P(T \leq t)$ one-tail	0.0084		0.4036		0.2661	
t critical one-tail	1.6573		1.6564		1.6564	
$P(T \leq t)$ two-tail	0.0169		0.8073		0.5323	
t critical two-tail	1.9794		1.9780		1.9780	

effect of age on the TH. It should be mentioned to avoid the effect of gender; men's TH data were used in this section. Figure 5 shows the relationship between age and TH in the male group. It can be seen that there is no relationship between them.

Figure 6 shows that the TH decreased as the DS increased. Table 6 shows that there would be a significant correlation between DS and TH (P value < 0.05).

4.4. Car-Following Models by considering Heterogeneity Factors. It was observed that two factors, gender and DS, were effective in CF behavior. The estimated CF parameters for all participants were averaged and then categorized based on the gender and DS, so three GM models were provided (Table 7).

For instance, based on the values of the estimated parameters, it is possible to draw a graph of deceleration based on distance. Now, it is possible to draw the graphs of CF models based on distance. Given that there are three independent variables in the GHR model, two variables must be considered fixed in order to draw a two-dimensional diagram. Therefore, the speed of the following vehicle and relative speed between two consecutive vehicles were considered 90 km/h and 20 km/h, respectively. By doing so, the relationship between deceleration and distance variable is plotted in Figure 7.

Figure 7 shows that the women applied greater deceleration than the men. In the men group, increasing the DS led to increasing the deceleration at an identical distance. In the figure, the acceleration values are negative and the sign is ignored.

Generally speaking, higher DS and female gender would lead to more aggressive behavior in deceleration CF behavior as they have led to intense deceleration. Moreover, it was observed that by increasing DS, the TH in steady-state CF was increased which would be an indicator for aggressive and unsafe behavior. According to the CF diagrams, it can be seen that gender and DS factors would be also effective in other driving behaviors.

Here, 0.5 m/s^2 was considered as the threshold of sensible deceleration which the driver applied intentionally (AASHTO; consider -3.4 m/s^2 as comfortable deceleration

FIGURE 5: Relationship between TH and age of drivers in steady-state CF.

FIGURE 6: Relationship between TH and DS of drivers in steady-state CF.

TABLE 6: Pairwise Pearson correlations of age-TH and DS-TH.

Sample 1	Sample 2	Correlation	95% CI for ρ	P value
Time headway	Desired speed	-0.965	(-0.994, -0.813)	≤ 0.001
Time headway	Age	-0.156	(-0.775, 0.616)	0.712

TABLE 7: The CF parameters based on gender and DS.

	c	m	l
Man and DS $> 95 \text{ km/h}$	0.3357	0.2697	1.1081
Man and DS $< 95 \text{ km/h}$	0.848	0.1758	1.2022
Woman and DS $< 95 \text{ km/h}$	0.752	0.2855	1.08447

[37]). In other words, decelerations less than 0.5 m/s^2 have been accidentally happened, because even in free driving situation, the driver cannot adjust her/his speed precisely and there is a fluctuation. Therefore, the threshold of CF behavior, which was assumed to be 90 m in this study, can be estimated.

Examining Figure 7, it can be seen that the CF diagrams of men and women at points 30 and 50 m were intersected 0.5 m/s^2 , respectively. Therefore, it can be concluded that the following TH at 90 km/h was 1.2 sec (men) and 2 sec (woman). This has been estimated averagely 1.5 in the previous studies; [4, 27]. This suggests that DS and age can also be effective in following distance threshold.

FIGURE 7: Relationship between deceleration and distance in different groups of drivers.

5. Conclusion

In this study, the effect of age, gender, and DS factors on CF behavior was investigated. DS was defined as the speed selected by the driver in free driving situation. A driving simulator was used to collect data. The CF model for each driver was calibrated by genetic algorithm. The estimated parameters were categorized based on the factors and analyzed using statistical tests. For further investigation, the effect of the DS factor on the TH in the steady-state CF was also examined. Considering the effect of factors, three GM CF models were provided and the threshold of the CF was investigated too.

The results of the research can be summarized as follows:

- (i) Gender and DS were effective in CF behavior, while the age factor was not.
- (ii) The sensitivity of drivers to the variables of speed and distance in the CF model increased with increasing the DS, while the magnitude of deceleration was higher in women.
- (iii) DS factor was effective in steady-state CF behavior. As the DS increased, the TH decreased.
- (iv) Women maintained larger CF threshold distance than men.
- (v) The DS can be considered as an indicator for aggressive behavior in deceleration CF and steady-state CF behavior.

Data Availability

Data used in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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